

BBC



NASA'S 10 CRAZIEST IDEAS REVEALED

How spider bots and Venus rovers will transform space exploration



Jetpacks:
here at last
Strap in, take off!

Hollywood
science

How big could movie
monsters *really* get?

FOCUS

SCIENCE AND TECHNOLOGY

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ISSUE 263

THE YEAR SCIENCE WILL
BLOW YOUR MIND

2014

COMET-CHASING SPACECRAFT, QUANTUM COMPUTING,
LIMITLESS ENERGY, ARTIFICIAL LIFE, AND MORE...

WHAT IS FIRE?

The discovery that sparked
a whole new science

WHY WE EAT TOO MUCH

How our brains trick
us to overindulge



SMART HEATING

We test the gadget that
could slash your fuel bills





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RYAN REYNOLDS

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SELF-ASSEMBLING MATERIALS, quantum communication and self-fertilising crops. These are just three of the exotic-sounding breakthroughs set to take the world by storm in 2014. We've uncovered some exciting stories from space science, neuroscience, genetics and more besides, so why not skip straight to p56 to find out about them?

Still here? Then let me tell you about NASA's most extreme ideas. These 'NASA

Innovative Advanced Concepts' include robot spiders in space, Mars landers that look like carpet tiles, and deep-space hibernation for astronauts. We look at whether they're feasible on p46.

Here on Earth, plans for solo flying machines date back to Leonardo da Vinci, but most designs that actually work have been flawed. Now, though, that could be about to change thanks to some innovative new machines. Get ready for take-off on p68.

If, like me, you've recently been ingesting too many calories (thanks to all that turkey, pudding and go-on-then-just-one-more after dinner mint), we'll give you some food for thought. On p40, Susan Aldridge examines the mounting scientific evidence into what drives us to eat too much.

And finally, if you listen to music digitally but you're disappointed by the sound quality of downloads and streaming, we have the solution. On p93 we review devices called DACs (Digital to Audio Converters) that plug into your computer to transform the sound of digital audio. Until next issue,

P.S.

Don't miss our February issue, on sale 9 January 2014

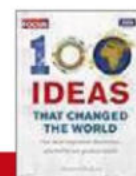
Graham

Graham Southorn, Editor

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APPEARING IN THIS ISSUE...



Susan Aldridge

Susan is a journalist specialising in health, genetic engineering and biotechnology and

is the editor of *Diabetes Update*. In this issue on p40 she looks into why we just can't stop ourselves from eating too much.



Stuart Clark

One of the UK's best-known astronomy journalists, and author of fictional

trilogy *The Sky's Dark Labyrinth*, Stuart returns to *BBC Focus* this month. He brings us up to speed with the latest in space research on p58.



Brian Clegg

Brian is a popular science writer whose books include *Dice World: Science and Life In A Random*

Universe, *Gravity: Why What Goes Up Must Come Down* and *How To Build A Time Machine*. He reveals next year's physics breakthroughs on p64.



Penny Sarchet

An award-winning science writer with a PhD in plant genetics, we tasked Penny with

bringing you some of 2014's most important breakthroughs. Turn to p60 to discover the gems she unearthed in stem cell technology and genetics.



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On p38 **Kathryn Jeffs** discusses what Antarctica can tell us about climate change, polar bears and alien life

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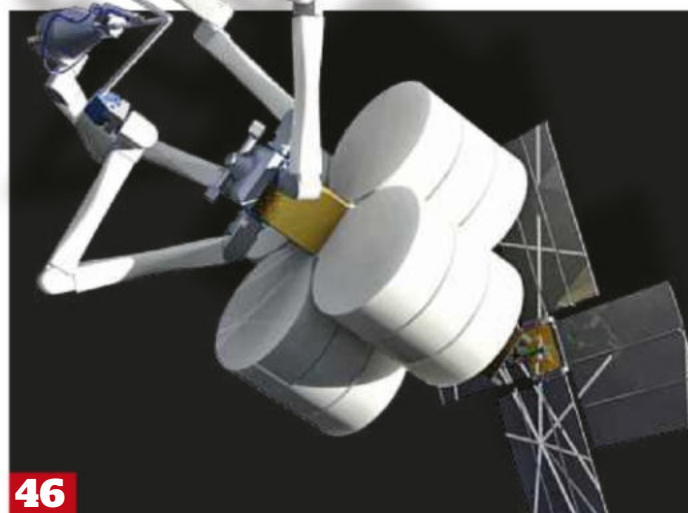
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MegaPixel



Chasing dreams

THE DREAM CHASER is a leading candidate to replace NASA's mothballed Space Shuttle. Only nine metres long, but capable of carrying a crew of seven and boasting a larger interior 'living space' than the Shuttle, the Dream Chaser is designed to launch into space on an Atlas V rocket.

During this test flight, the space plane was suspended from an

Erickson Air-Crane helicopter, allowing engineers to evaluate its aerodynamics and the performance of various subsystems. "This was a key flight test to check several of the onboard systems of the Dream Chaser spacecraft, including the guidance, navigation and control, aero surfaces and landing gear," says Mark Sirangelo, head of Sierra

Nevada Corporation's Space Systems division, which is developing the spacecraft.

The craft still has to run a gauntlet of tests to ensure that everything is up to spec before it can go to work. It recently skidded off a runway after its landing gear failed to deploy properly following an unmanned flight test.

PHOTO: SIERRA NEVADA



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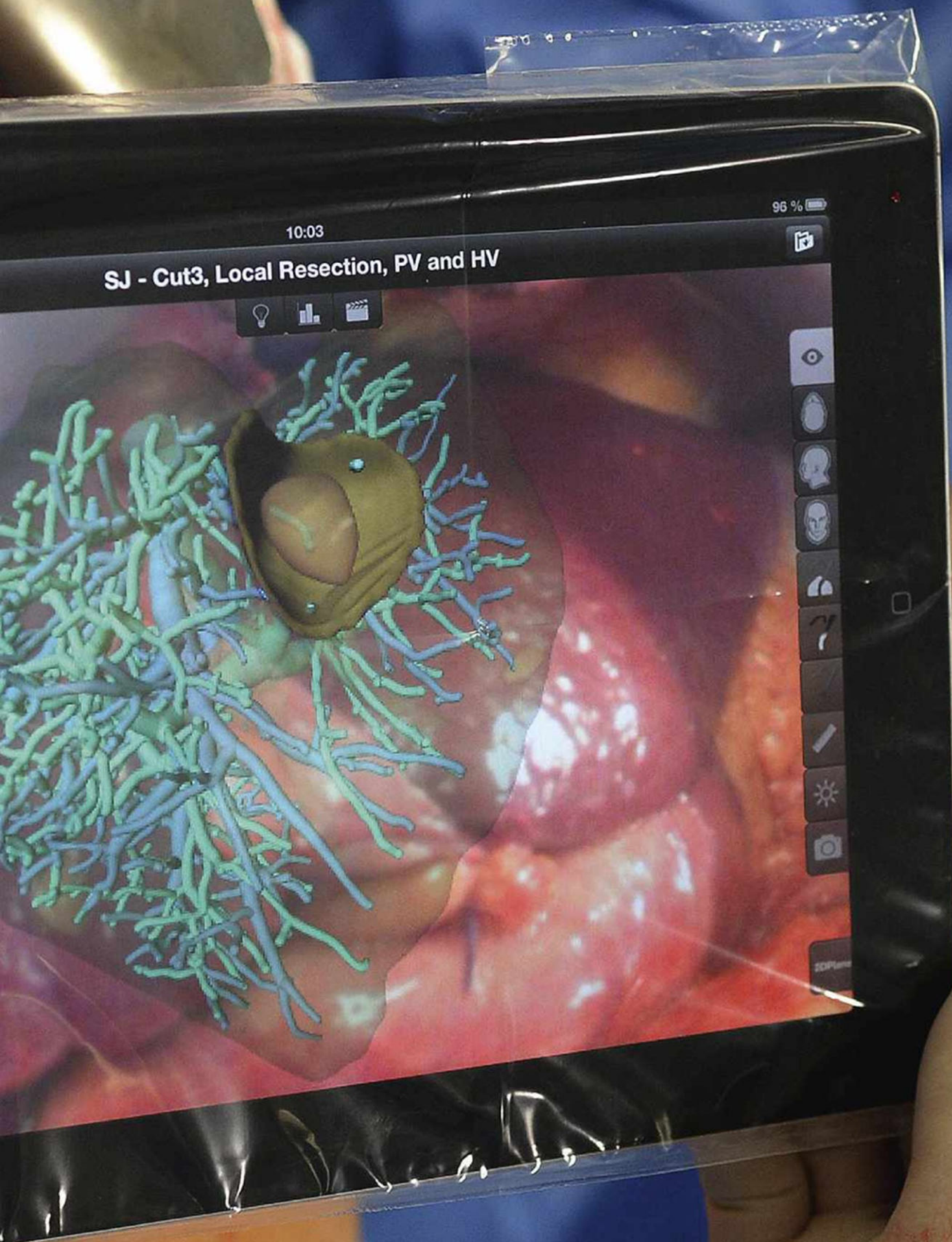
MegaPixel

Augmented organs

THIS AUGMENTED REALITY iPad app promises to save lives by making liver surgery safer. The liver is a blood-rich organ and severe bleeding is a major risk during surgery. To reduce the risk, surgeons plan the operation in advance, taking into account the exact anatomy of the patient's liver, but once in the operating theatre they can only rely on still pictures and their memory. This app, developed by Fraunhofer MEVIS, offers a helping hand by giving surgeons real-time, interactive access to the patient's data.

Not only can doctors easily take their plans into the operating theatre with this app, "they can adjust these plans quickly and flexibly in the operating room when needed," says Bianka Hofmann of Fraunhofer MEVIS. "Virtual and real organs can be overlaid: the liver is filmed with the tablet computer and, using augmented reality, virtual planning data can be semi-transparently superimposed onto the organ in real-time."

PHOTO: CORBIS





MegaPixel

Jet flight

SEEN IN ACTION is Belgium's Ludovic Lucas, demonstrating the latest extreme sport: flyboarding. Invented by Francky Zapata, the Flyboard was developed in the spring of 2011 and is inspired by jet-skiing and acrobatic diving.

The device consists of a board attached to a pair of shoes on one side and a jet-ski turbine on the other. This provides 90 per cent of the propulsion, with the last 10 per cent coming from two water jets on the user's forearms that are attached to the turbine by pipes. This allows additional stability and manoeuvrability, although according to Lucas, improvements to the technology are planned "to make it lighter, less bulky and more manoeuvrable."

"It requires a lot of power to lift a man," says Lucas. Indeed, to keep the rider seemingly flying over the surface, the machine delivers 300 horsepower to move up to half a tonne of water a second.

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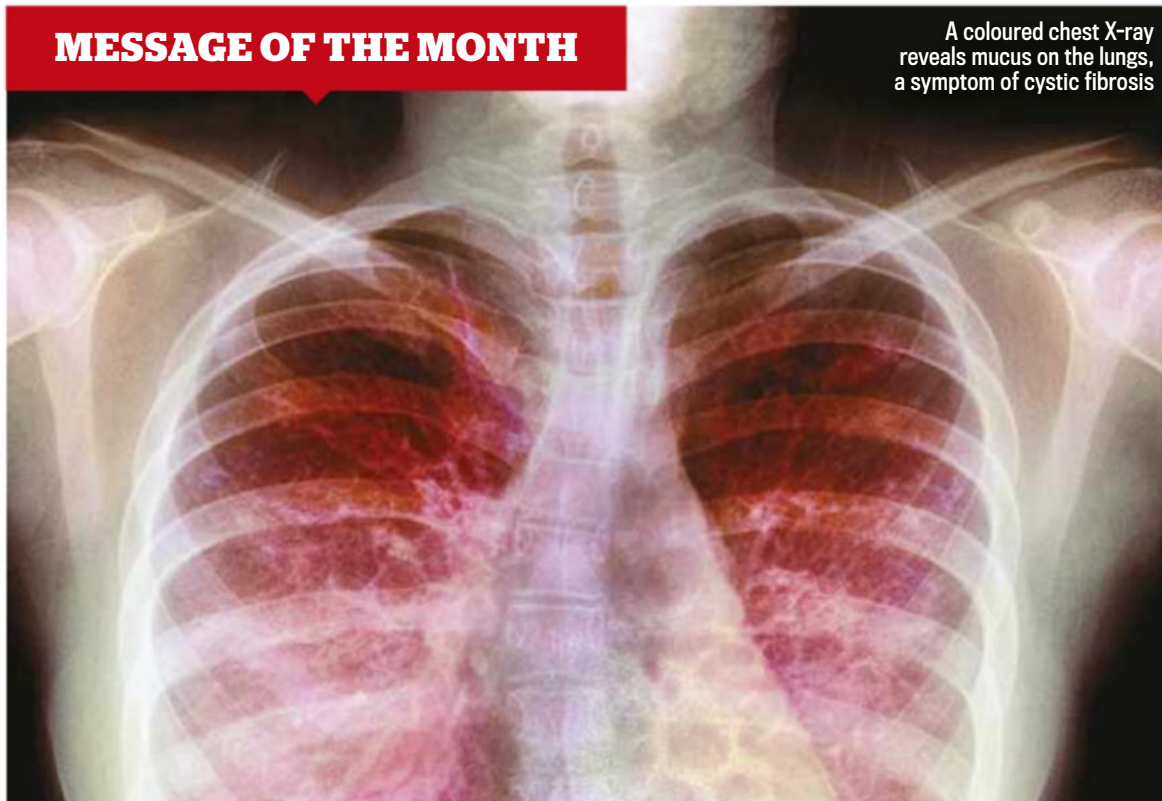


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Letters may be edited for publication

MESSAGE OF THE MONTH



A coloured chest X-ray reveals mucus on the lungs, a symptom of cystic fibrosis

Survival of the moderates

When reading Haley Birch's article concerning present and future evolution (November, p42), I enjoyed the piece referring to the negative pressures that force a species down one evolutionary path or other. Specifically, the acquisition of the heterozygous form of sickle cell anaemia to combat malaria. I am reminded of a similar situation regarding cholera infection and cystic fibrosis, a congenital, genetic disease affecting the lungs and digestive system.

There is a hypothesis that cystic fibrosis carriers have greater resistance to cholera and thus they should have been selected over what were otherwise known as 'healthy' individuals during periods when cholera epidemics were rife. It explains why there is such a high level of cystic fibrosis

in the population and shows that perhaps evolution didn't 'fail' to eradicate a specific genomic trait. Instead there was a clear decision to maintain a trait that allowed for survival. We often associate evolution with survival of the fittest. But our perception of what designates fitness and health are so often out of lockstep.

And so with further respect to Hayley Birch's piece referring to evolution and AIDS, perhaps a super immune system is not the answer. Maybe those with a perceived genetic weakness might be the ones to evade present and future diseases. If we cannot come to a cure and biological conditions call for it, then perhaps the genetically meek will inherit the Earth.

Seán O'Callaghan

Evolution in space

I was thrilled to read the article 'The Future Of Us' by Hayley Birch (November, p38). The fact that we could improve upon evolution is fascinating. As stated in the article, we could become healthier or more intelligent in the future. We could even evolve into another human species in outer space to the extent that if the latter lives in space for centuries, it may no longer be able to procreate with mankind on Earth. I believe we should intervene in the evolution of human life through medical and genetic improvement, but I still think that we should allow evolution to take its own course.

Matthew Caruana, Malta

Muslim pioneers

I enjoyed reading 'The Future of Us' article and I respect giving recognition to Alfred Russel Wallace. Credit should also be given to the original sources of evolution – Muslim scholars. European scientists followed Roger Bacon's advice to 'learn Arabic and Arabic science for progress' and Arabian books were translated into European languages around 1650-1700. One Arabian scholar, Al Jahiz (776-869), wrote *The Book Of Animals*, which made observations that described evolution very clearly. Ibn Khaldun wrote the *Muqaddimah* (1377) in which he asserted that humans developed from 'the world of monkeys'. Ibn Sina's *Canon Of Medicine* was the chief textbook of medicine in European medical schools until the 17th Century and Al-Haitham had many contributions to science, and there are many more. These were all God-believing evolutionists, which I personally find fascinating and think it is only fair to share these scholars and their teachings with all the readers out there!

Vicki Meigh, Worcester

But how do we know?

I normally enjoy 'How do we know?' – I have thought the series would make a good popular science book because the articles usually summarise the evidence for the theory being discussed in terms that a layman can follow. However, the most recent 'How do we know... The Theory of Evolution' was deeply disappointing



Write in and win!

The writer of next issue's Message of the Month wins a Linksys PLEK500 Powerline HomePlug AV2 kit worth £89. It uses your home's power sockets to provide a high-speed internet connection without cables – perfect for online gaming and video streaming in HD. www.linksys.com/en-eu/home



(November, p112). It is essentially a history of a philosophical concept (natural selection/survival of the fittest), which provides a rationale for the mechanism of evolution. Unfortunately, despite the title, it doesn't actually give any evidence as to why evolution is true. As I read it, behind my shoulder I could hear the creationist mantra of: "Where's the evidence?"

Ron Gardner, Ludlow

You're right, there was less of the 'how' in this installment. As the mechanism for evolution is all Darwin's, we wanted to pay tribute to earlier men with evolutionary ideas. – Ed

Magic bus

In 'How it works' on the road-charged electric bus (November, p77), I was surprised to read: "This allows current to flow between the two [coils], charging the battery." If this were true, significant sparks would be seen jumping between road and vehicle! Of course, what was meant was that energy passes from the road coil to the one on the bus, but there is definitely no electric current passing - which is actually the whole point of the system. Otherwise, it was a fascinating insight into this new technology.

Alan Turk, Swindon



South Korea is testing electric buses that are able to receive power wirelessly as they move over a specialised road

How to stop poaching

It seems impossible to stop poaching, so why not take a different approach? If elephants were 'detusked' it would at least save the animals, and the ivory could be sold to fund their protection. Alternatively, is there any way of 'contaminating' live ivory so it becomes worthless as Chinese medicine? If there is no profit, there is no poaching.

Jeff Dobson, Reading

Appliances of science

I always read your 'Appliances of science' feature with a wry smile. How many of us make full use of the power and storage of

the technology around us? I used every inch of my first mobile phone back in the late '90s, from making calls to killing time on the snake game. I barely scratch the surface of what my powerhouse of a phone can do now. Unless you are editing HD footage, do we really need all this power? Or have I just hit that age where one harks back to ZX Spectrums and Commodores?

Mark Radford, Ramsbottom



YOUR COMMENTS ON TWITTER & FACEBOOK

We asked: which *Doctor Who* science and inventions do you most want to come true?

@cinnamaldehyde A sonic screwdriver. I'd give almost anything for a sonic screwdriver.

@FarrahStoner The screwdriver. It's like a pocket size guy who does all the fixing around the house, it identifies things, and it's a weapon.

@ResurgenceTees No one mentions the TARDIS [despite all the inevitable Time-Space apocalypses we'd bring with it]? For shame!

@FernwehFreya That sonic screwdriver of course! But no angels!!

@Lotus_HR Has to be time travel, so I can get all my work done :-).

Ross Kobak Reversing the polarity of the neutron flow so I can go back in time and think of a better suggestion.

Stuart Williams K9 - a genuine cyber pet and personal assistant.

Louise Rutland Time travel and parallel universes. It would be interesting to see the world where I became an architect, which I wanted to do as a kid.

Andrew Rubotham Transdimensionally engineered housing to house many more people in a smaller space, alongside farms that were bigger inside their boundaries than the fences would suggest. Having all houses looking like police boxes would be optional.

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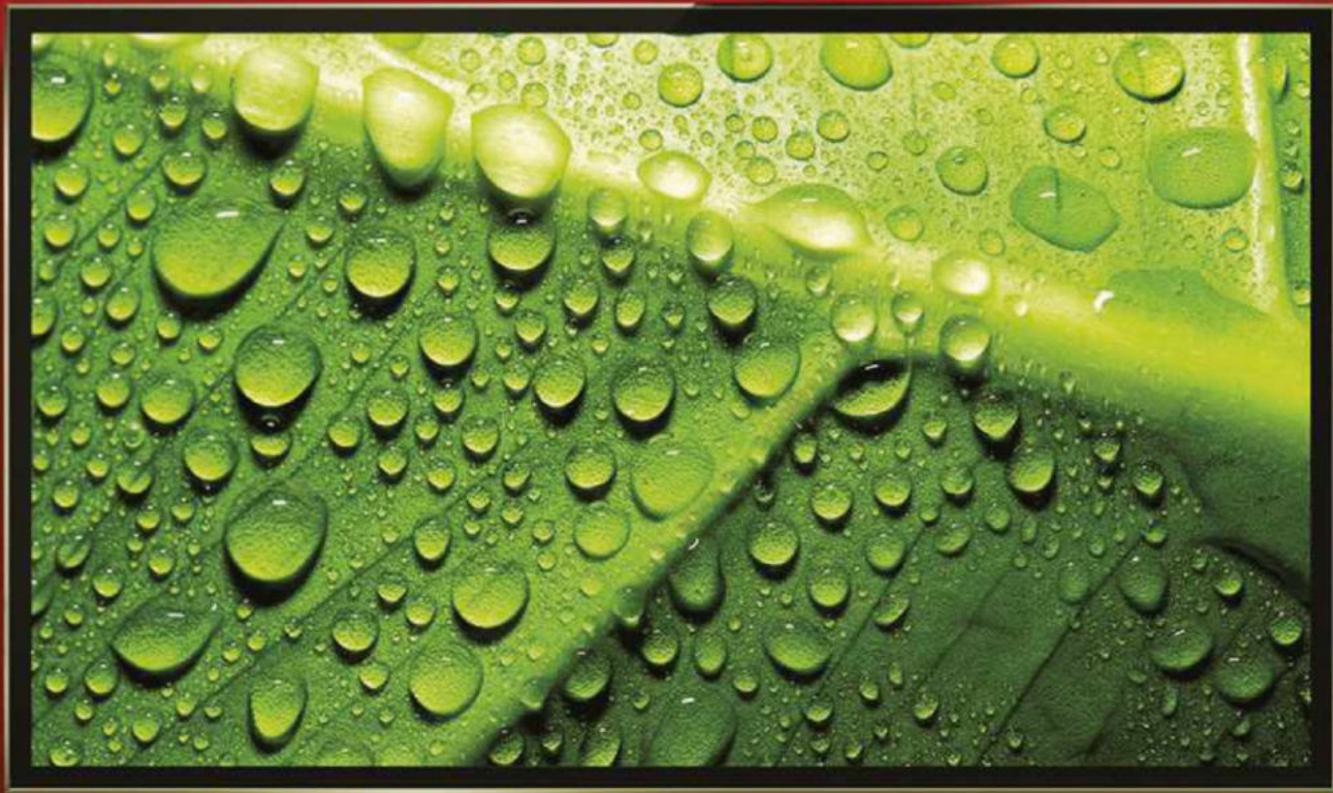
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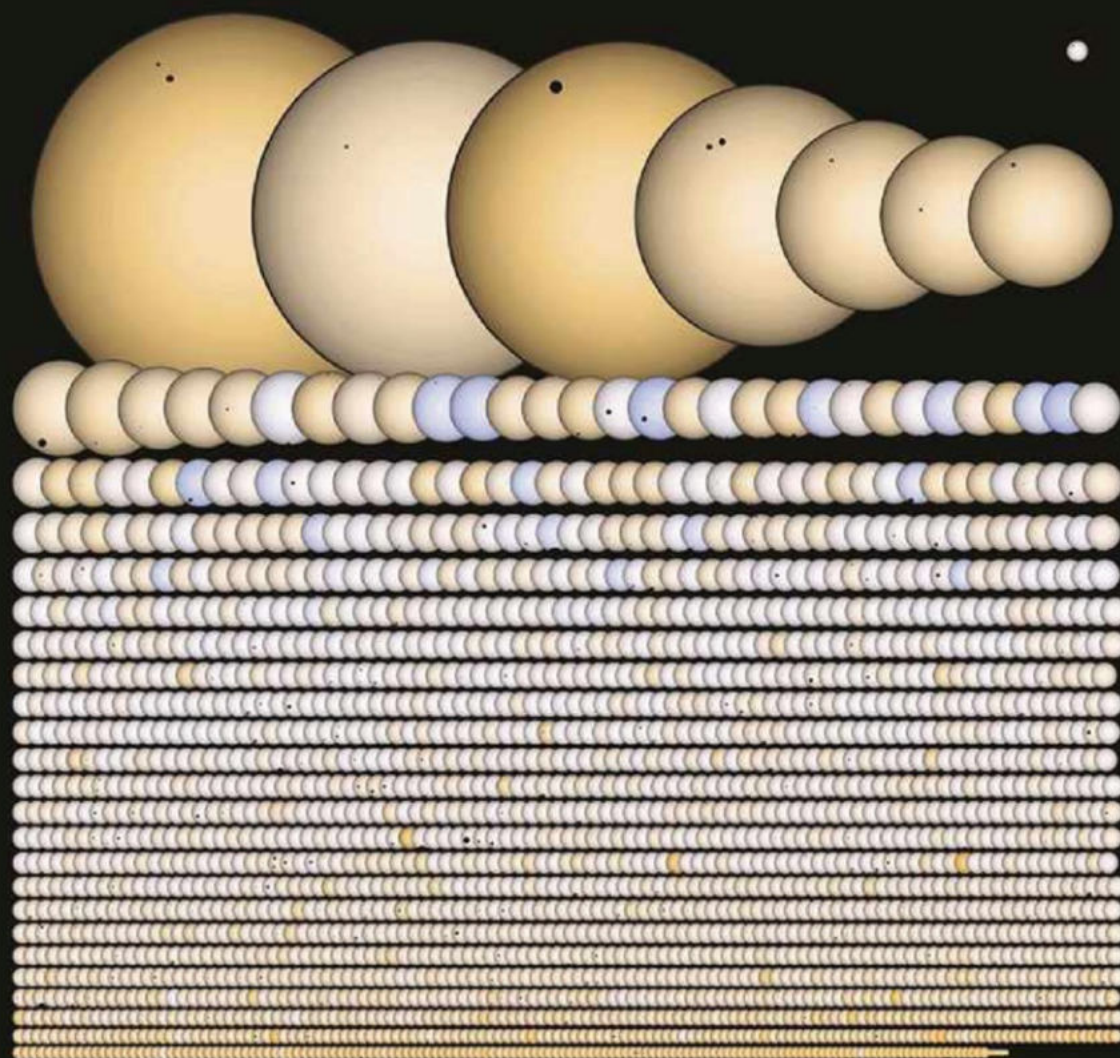
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Kepler's huge haul of planets are seen as dots passing in front of their parent stars, shown here in order of relative size

THE BIG STORY

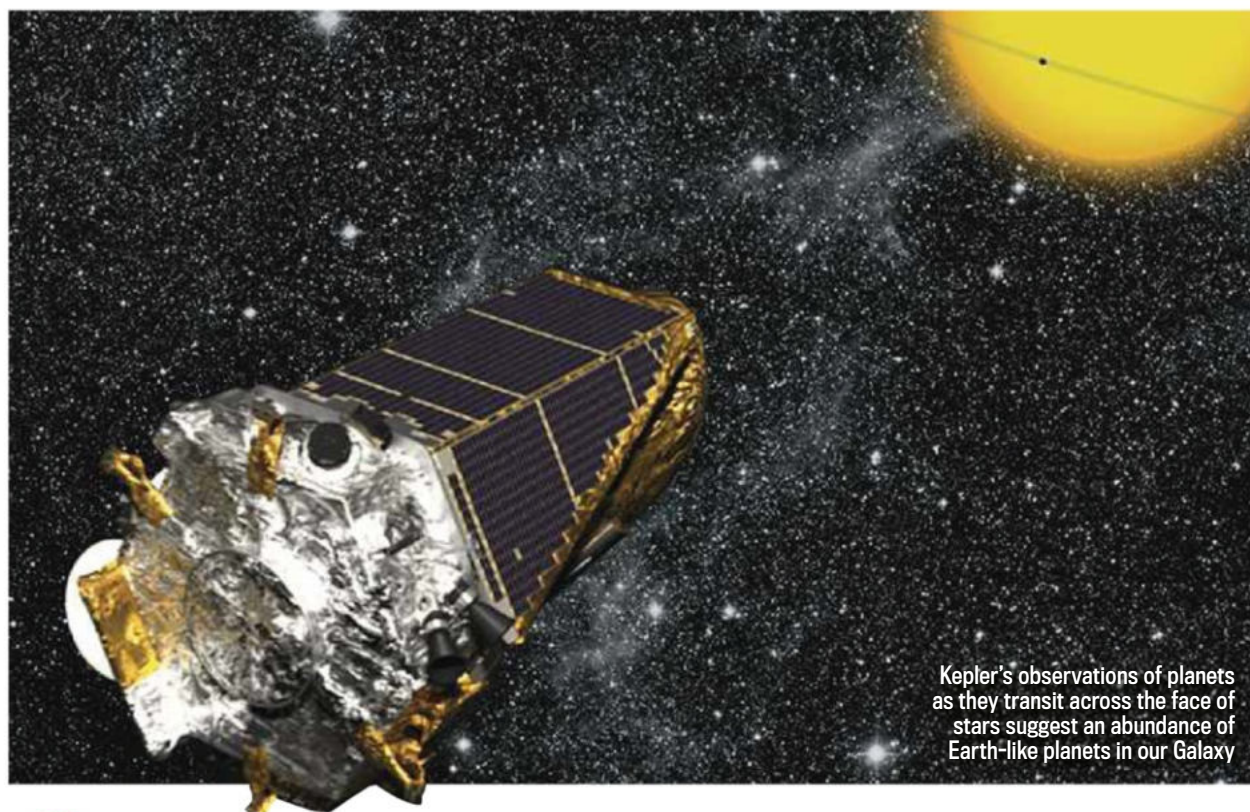
GOLDBLOCKS PLANETS PEPPER OUR GALAXY



Planets that are 'just right' for life to exist could be common. As many as one in five Sun-like stars could have them, according to the latest results from NASA's Kepler Space Telescope



PHOTO: NASA



Kepler's observations of planets as they transit across the face of stars suggest an abundance of Earth-like planets in our Galaxy



ASTRONOMERS ANALYSING data beamed back from NASA's Kepler Space Telescope have predicted that a fifth of the Sun-like stars surveyed in the Milky Way have so-called 'Goldilocks' planets orbiting them.

'Goldilocks' planets are Earth-like worlds where conditions are 'just right' for the existence of life. Such planets need to have a surface temperature that allows water to exist as a liquid, which means being neither too close nor too far from their star.

The findings were announced by University of California, Berkeley astronomer Erik Petigura. "When you look up at the thousands of stars in the night sky, the nearest Sun-like star with an Earth-size planet in its habitable zone is probably only 12 light-years away and can be seen with the naked eye. That's amazing," he said. A light-year is the distance light travels in one year, and the nearest star to the Sun is Alpha Centauri, 4.4 light-years away.

The Kepler Space Telescope was launched in 2009 on a mission to scan the Milky Way for Earth-like worlds. It has continuously monitored more than 150,000 stars, measuring their brightness every 30 minutes. Researchers spot planets by using the readings taken by Kepler to look for the minute dips in a star's brightness caused by a planet 'transiting' in front of it.

The task is made harder by the many stars that fluctuate in brightness too much for a planet's transit to be detectable. So Petigura and his team examined 42,000 of the stars with the smallest fluctuations. They found 603 planets, of which 10 were Earth-size and lay in the habitable zone. The drawback of the transit method is that it only detects planets orbiting in the same plane as the host star – a small fraction of the total number. After the numbers were crunched to account for planets that would have been missed, the team estimated that 22 per cent of Sun-like stars they observed have potentially habitable Earth-like planets.

So far, researchers have only made it through the first three years of Kepler's observations. The team expects the remaining data is likely to contain further revelations.

"The planets we have already found are of a bewildering variety," said William Borucki, a scientist at the Ames Research Center. "We have planets that are probably entirely composed of water, some that are smaller than Mercury and some that are bigger than Jupiter. Some have densities that are greater than iron and we've found some with densities lower than Styrofoam. Kepler has only searched 1/400th of the sky. Imagine what other missions will find as we continue that exploration."



TIMELINE

A brief history of the search for other Earths

1992

The first two exoplanets are discovered in orbit around PSR B1257+12, a pulsar lying 980 light-years away from Earth in the constellation of Virgo.

1995

51 Pegasi B becomes the first planet found in orbit around a so-called 'main sequence' star similar to the Sun.

2007

NASA's Spitzer Space Telescope finds water vapour on an exoplanet for the first time in the atmosphere of HD 189733b.

2009

The Kepler Space Telescope is launched with the aim of searching the Milky Way for signs of habitable Earth-like planets.

2011

Kepler-22b is discovered, the first exoplanet that lies within its star's habitable zone. It is twice the size of Earth.

2013

The first Earth-sized planets are discovered within their stars habitable zone, Kepler-62e, 62f and 69c.



ANALYSIS

Suzanne Aigrain



Astrophysicist from All Souls College, University of Oxford



THE RESULTS ARE interesting but I would say there is still a fair amount of uncertainty in the number. They basically took all the planets Kepler has detected and then worked out how many planets they might have missed, either because they didn't transit or because the data wasn't sensitive enough to show them. That enabled them to work out just how many planets per star there are on average.

The reason I think there is a certain amount of uncertainty is that there are only a few planets in that region so they had to do some extrapolation. They did it in a sensible way but extrapolation always carries a certain risk. The number is potentially exciting because it's so high. But it's still possible that figure might change in the future.

The study used almost all of the data, but everybody agrees that there are probably ways of improving the analysis of the data. There are still some effects caused by the instrument itself that we're learning to correct better, and we're also learning more about the properties of the stars through complementary ground-based observations. This will all probably lead to a more sensitive study. It's likely that there are still quite a few more planets to be found within the data, and finding them will give us a better estimate of just how many planets there are in the habitable zone.



WHAT DO YOU THINK?

Do you think we'll eventually find life on Earth-like planets? Give us your views at facebook.com/sciencefocus or email reply@sciencefocus.com

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Climate change

Temperature rise means shrinking size

The fossilised jawbone of the early horse *Hyracotherium*

THANKS TO RISING sea levels, droughts and extreme weather events, climate change is likely to have a significant impact on the planet in years to come. But an increase in global temperature could also have an effect on humans: it may make us shrink.

Fossil records show that mammals such as primates and horses shrank significantly during at least two ancient global warming events. Once during the Paleocene-Eocene Thermal Maximum (PETM), about 55 million years ago, and again about 2 million years later during the Eocene Thermal Maximum 2 (ETM2).

"The fact that it happened twice significantly increases our confidence that we're seeing cause and effect. One interesting response to global warming in the past was a substantial decrease in body size in mammalian species," said Prof Philip Gingerich, a

paleontologist at the University of Michigan.

The shrinking effect also seems to be related to the magnitude of the warming event. During the PETM temperatures rose 9–14°C. This led to the *Hyracotherium*, an early horse, reducing in body size by 30 per cent. Due to the 5°C rise of the ETM2 the same species shrank by 19 per cent. After both events, the animals rebounded to their pre-warming size.

Gingerich has proposed that the effect may be due to the plants eaten by the mammals during periods of elevated carbon dioxide levels having a lower nutritional value.

*Hyracotherium* shown nose to nose with a modern day horse

Environment

Search for oldest ice heats up

TRACKING DOWN THE oldest ice cores on Earth can be a tricky business. In some places the ice is too thin, in others it's too thick. Some areas are too warm due to geothermal heating so vital layers are lost due to melting. Horizontal movement of the bedrock can also mix up the ice, making it impossible to read.

Thank goodness, then, that someone has already done much of the hard work. Scientists have identified a region in Antarctica that is possibly 1.5 million years old, almost twice as old as the ice core drilled to date.

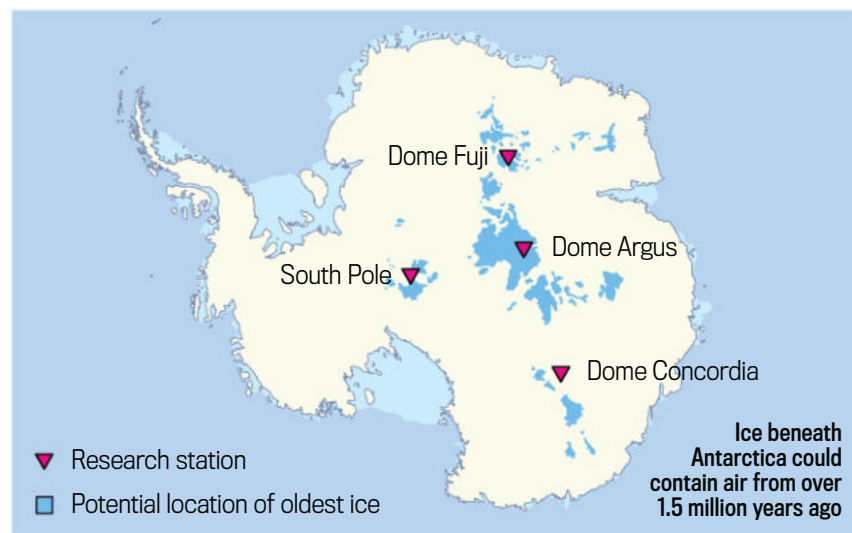
"To constrain the possible locations where 1.5 million-year-old, and undisturbed, ice could be found in Antarctica, we compiled the available data on climate and ice conditions. We then used a simple ice and heat flow model to locate areas



The older the ice core, the further back in time scientists can study

where such old ice may exist," says the British Antarctic Survey's Professor Eric Wolff.

The bubbles of air locked inside ice cores provide researchers with a direct record of the Earth's climate. By studying these bubbles they can figure out how the concentration of greenhouse gases in the atmosphere affects the temperature, and more accurately predict the effects of man-made climate change.



THEY DID WHAT?!

Rats hooked on slot machine gambling

What happened?

Lab rats at Canada's University of British Columbia were trained to play a slot machine-style device

consisting of three lights. If all three lights lit up, they won some sugar pellets, which they could collect by pressing a lever to 'cash out'. If one or two of the lights lit up, nothing happened.

What did the rats do?

The rats tried to cash out when two lights were lit almost as often as for legitimate wins. Researchers likened this to the

'near-miss' scenarios, such as a Blackjack hand of 20, that produce a similar buzz to winning in the brains of human gamblers.

What was the point?

When drugs blocked the rats' dopamine receptors the tendency for two-light cash outs was reduced. This suggests similar drugs may help gambling addicts keep their money in their pockets.



One-armed bandits are helping research into gambling addiction

Dinosaurs

Prehistoric giant walks again



A reconstruction of *Argentinosaurus* skeleton at the Museo Municipal Carmen Funes, Neuquén, Argentina

THANKS TO A laser scanner and some serious computing power, the gigantic *Argentinosaurus* is walking again for the first time in 100 million years. Researchers at the University of Manchester fed scan data of the 40m, 80 tonne giant's skeleton into a specially designed computer with the processing power of around 30,000 desktops. They used custom-made learning software to predict the most likely movement

patterns, before using them to create an animation of the beast walking.

Lead researcher Dr Bill Sellers said: "If you want to work out how dinosaurs walked, the best approach is computer simulation. This is the only way of bringing together all the different information we have on this dinosaur, so we can reconstruct how it moved."

The prehistoric behemoth wasn't quick on its feet – the

simulation shows it could reach a maximum speed of 8km/h (5mph) – no surprise given it weighed as much as seven double-decker buses.

Sellers says the research is important for understanding our own musculoskeletal system and also for the future development of robotics.

The team now intends to use the same method to recreate the steps of other dinosaurs such as the *Triceratops* and *T. rex*.

Walking with dinosaurs: a simulation provides insight into the *Argentinosaurus*'s gait



1 MINUTE EXPERT

Thorium

What's that? Something to do with the hammer-wielding superhero?

Kind of. It's a radioactive element that has been suggested for use in nuclear reactors as a safer alternative to uranium. It was named after the Norse god of thunder following its discovery by Norwegian mineralogist Morten Thrane Esmark in 1828.

How safe is it?

Thorium reactors are easier to shut off than uranium ones. If the fuel rods fail to contain the chain reaction, as occurred in Fukushima, a thorium reactor can be stopped by cutting off the smaller uranium or plutonium feeder used to stimulate it. Also, thorium waste remains radioactive for a much shorter period and can't easily be used in weapons.

What's the catch?

Thorium is fertile rather than fissile. This means it doesn't split into smaller elements when bombarded with low-energy neutrons like uranium does. This splitting releases the energy bound up in the fuel's atoms. Fertile materials are instead used as a starting point to generate fissile materials.

WHO'S IN THE NEWS?



Prof David Nutt

Director of the Neuropsychopharmacology Unit at Imperial College London

• **What did he say?**

Nutt condemned UK drug laws for holding back research into illegal drugs. He claims the research is essential as it could lead to the discovery of new treatments for neurological

conditions such as depression and Parkinson's disease.

• **How so?**

Scientists who want to research substances banned by the Misuse of Drugs Act have to apply for a licence. Obtaining one costs thousands of pounds and can take as long as a year. According to Nutt, the expense and red tape are putting pharmaceutical companies off.

• **Is there any evidence of illegal drugs having legitimate medical uses, or is Nutt off his nut?**

Studies carried out during the 1950s found that LSD, otherwise known as acid, could be effective in the treatment of alcohol addiction. More recently MDMA, the chemical name for ecstasy, showed some promise in treating Parkinson's disease and post-traumatic stress disorder.



PATENTLY OBVIOUS with James Lloyd

Inventions and discoveries that will change the world



The world is your (virtual) playground

IMAGINE A VIDEO games console that not only tracks your movement – à la Microsoft's Kinect – but also sees through walls. Wearing a VR headset, you could take cover in the bathroom to hide from brain-sucking aliens, or hunker down under the stairs until nuclear Armageddon has passed by.

That's the promise of 'WiTrack', which monitors your motion by reflecting radio waves off your body. A patent application for the device was recently filed by researchers at the Massachusetts Institute of Technology. By measuring the time taken for the radio signals to reflect back to the receiving antennae, the device can calculate where you are. And because it uses radio waves, it can follow you through walls.

As well as video games, the technology – which currently locates a human body to within about 10cm – could also detect when an elderly person has fallen, or allow you to control household appliances from anywhere in your home. **Patent application number: TBA**

The silent hairdryer

BRITISH ENGINEER JAMES Dyson's latest project could make those early mornings a much more peaceful affair: he's working on a silent hairdryer. A patent describes how the hairdryer will be lined with a foam or felt-like material that's tuned to absorb the dryer's roar. The device also boasts a nifty design that separates the airflow through the hairdryer into two paths. This means that only around half of the air passing through the dryer goes through the fan, further quieting the device.

Patent number: US 20130269201

The microphone tattoo

TIRED OF BEING drowned out by rumbling cars and chattering crowds when you're trying to speak on your smartphone? Why not tattoo a microphone onto your throat? As crazy as it sounds, Motorola is patenting an 'electronic skin tattoo' that incorporates a microphone and a transceiver to wirelessly communicate with your phone. The idea is that by picking up vibrations directly from your larynx, the background noise will be reduced. Just make sure you don't cough.

Patent number: US 20130297301

Biology

Life from earth

IT'S SURELY ONE of the biggest mysteries of all time: how did life originate on Earth? Now, scientists may be a step closer to finding out after the chance discovery that clay may have acted as a breeding ground for the chemicals that form the building blocks of life.

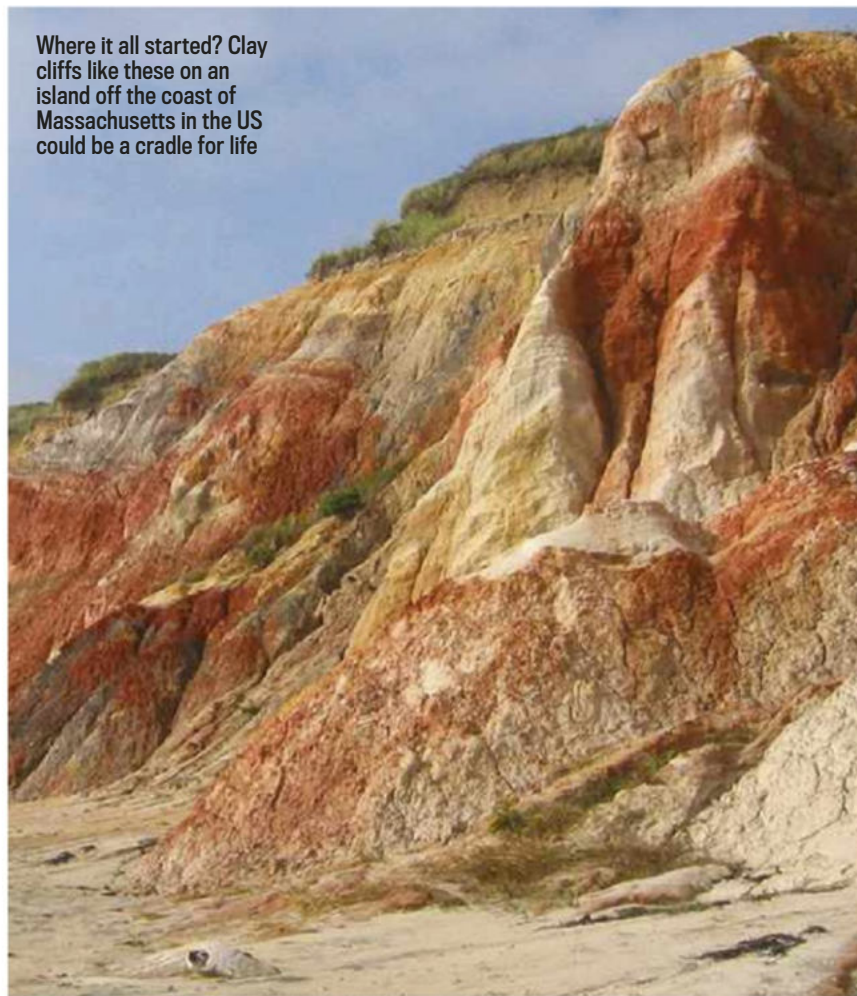
Researchers from New York's Cornell University stumbled upon the idea after using clay hydrogels in the production of proteins. The team noticed that the clay boosted protein production, leading them to think it might provide the answer to a long-standing question concerning the evolution of biomolecules.

"In simulated ancient seawater, clay forms a hydrogel – a mass of microscopic spaces capable of soaking up liquids like a sponge," the paper's author Dan Luo explained. "Over billions of years,

chemicals confined in those spaces could have carried out the complex reactions that formed proteins, DNA and eventually all the machinery that makes a living cell work. Clay hydrogels could have confined and protected those chemical processes until the membrane that surrounds living cells developed."

Earlier experiments have shown that amino acids and other biomolecules could have been formed in primordial oceans, drawing energy from lightning or volcanic vents. But it was uncertain how these molecules could go on to form more complex structures, and how they were able to survive the harsh conditions. Clay is a promising possibility because biomolecules tend to attach to its surface. The hydrogel structure helps to protect the delicate contents from damaging enzymes that might strip down and destroy DNA.

Where it all started? Clay cliffs like these on an island off the coast of Massachusetts in the US could be a cradle for life



Food science

Patties without the podge

IT'S EVERY MEAT lover's dream, a nice juicy burger that can be enjoyed without the accompanying risk of an expanding waistline. Well, that dream may soon be realised as researchers have found a way to pack reduced-fat mince with meaty flavour.

According to a study published in the journal *Meat Science*, plasma proteins taken from beef can be used to replace fat in mince without adversely affecting the taste.

The proteins were obtained from the meat through ultra-filtration and freeze-drying and then combined with inulin, a type of carbohydrate often found in



Mmmmm... mince. And now with the added benefit of helping you keep the pounds at bay

chicory. The resulting concoction was then added to reduced-fat mince and fed to a group of taste testers. The process had no observable effect on colour, flavour, taste or texture and fared well when pitted against full-fat mince despite containing 20 to 35 per cent less fat, the paper says.

Zoology

Nasal navigation

The humble pigeon follows its nose to find its way home



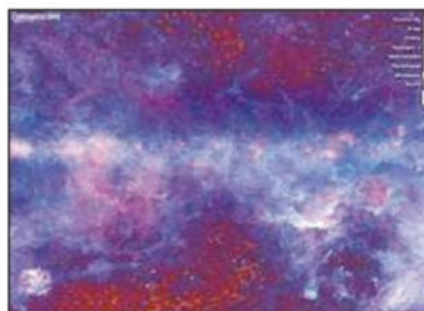
EVER WONDERED HOW pigeons can find their way home having been released hundreds of kilometres away? It turns out they may be simply following their noses. Hans Wallraff of the Max Planck Institute for Ornithology in Seewiesen, Germany, has developed a theory that pigeons are able to smell their way by accurately perceiving the ratios of various scents given off by organic compounds. The pigeon is then able to find its way by associating certain smells with wind directions.

"If the percentage of a compound increases with southerly winds, a pigeon learns this wind-correlated increase. If released at a site some 100km south of home, the bird smells that the ratio of the compound is above what it is on average at its loft and flies north," Wallraff explains.

In order to test his theory Wallraff made a computer model based on atmospheric data. In this simulation, virtual pigeons were able to navigate successfully armed only with knowledge of winds and odours.



CLICK HERE with Kelly Oakes
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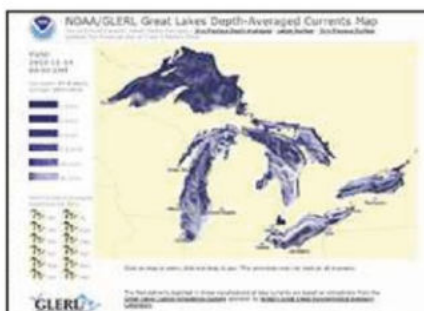


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www.nobelprizeii.org

Whether you're a scientist or not, these videos will let you get inside the head of some Nobel prize winners, and hopefully give you a bit of inspiration. If things are not going your way, the 'Surprises

and Setbacks' section shows that even failed experiments have value and Nobel prize winners are mistake-making humans too.



GREAT LAKES CURRENTS MAP

www.glerl.noaa.gov/res/glcfs/currents/glcfs-currents-avg.html

Watch North America's Great Lakes come alive in real-time with this National Oceanic and Atmospheric Administration site that visualises the average current

speed right now and over the last three hours. You'll never need this information, but that doesn't stop it being captivating.



DART OF PHYSICS

www.dartofphysics.ie

Did you know that everyone on your train carriage is attracted to you? Okay, okay, only gravitationally. If you've visited Dublin since the end of October you might have seen this fact on a 'dart of physics' poster on public transport. If not, never fear – the website contains many more to keep your mind occupied. Find out why the Moon is escaping the Earth, why we are all made of stardust, and more.



KELLY OAKES is a science journalist who tweets from @kahoakes

HOT TOPIC



Scientists pose with their creation – the world's first cloned dog Snuppy

Cloning

Would you clone your pet?

ARE YOU A dog owner that couldn't live without your beloved pooch? Thanks to a South Korean biotech company you may not have to.

Seoul-based Sooam Biotech Research Foundation is launching its service in the UK by holding a competition for one dog owner to have their canine companion cloned.

Sooam usually charges around £60,000 for each duplicate dog and claims to have successfully cloned more

than 200 animals for wealthy Americans and a number for the South Korean Police Force.

According to Sooam's website: "Cloning technology is possible at Sooam for any dog, no matter its age, size, and breed. Sooam not only performs dog cloning research, but also heals broken hearts."

To produce the clone, a Sooam scientist will take a skin sample from the target dog, inject DNA from that sample into another dog's egg cell

that's been emptied of DNA, and then implant the embryo into the womb of a surrogate.

However, many critics have spoken out, stating that current cloning techniques are unreliable. It can take more than 100 attempts to produce a healthy animal, and even then conditions in the womb and other environmental factors can have a dramatic effect on the resulting dog's appearance and personality.

Professor Chris Mason, Chair of Regenerative Medicine Bioprocessing at University College London said: "Snuppy, the first cloned dog, was born in 2005 being the only survivor of over 1,000

WHAT DO YOU THINK?

Let us know your opinions at facebook.com/sciencefocus and twitter.com/sciencefocus



Ross Kobak

The 6th Day [movie] anyone?



@rich_141 I have a

pet dog, Bella. She is a quirky and fun

bundle of fur. Cloning wouldn't replicate her character nor her temperament.



Donna Evil-d

Williams Good grief.

Do you really think I'd want more than one Merlin?!

cloned embryos implanted into 123 dogs. This low efficiency reflects the high degree of difficulty in cloning dogs and is okay for proof of concept. If the South Korean team has progressed from an almost chance event to a robust reproducible cloning process in a few years, this would be a major achievement.

"Will the cloned family dog be the same as the original? Unfortunately not – while genetically identical, the environmental factors will always be different. A cloned Rover will not be the same Rover, but Rover version 1.1 – a unique dog rather than a carbon copy."

NEWS IN BRIEF

Snaps predict storms

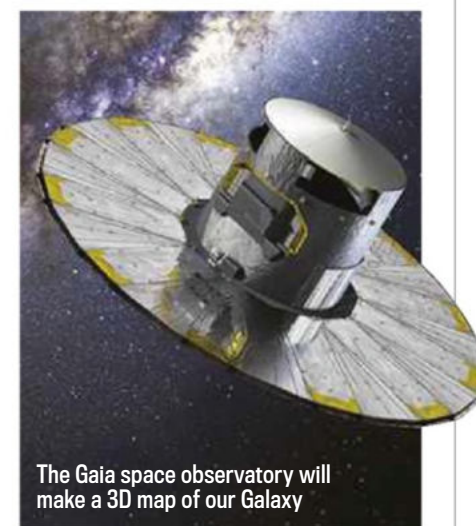
It seems Hurricane Sandy didn't dampen the public's enthusiasm for taking photos, a finding that could help governments measure the impact of future disasters. According to photo-sharing website Flickr, 32 million Sandy-related snaps were posted using its service in 2012. Researchers from the Warwick Business School found a strong correlation between the storm's severity and the number of photos uploaded.

New part in your knee

It might be time to rewrite the anatomy books. Belgian researchers have found a hitherto unknown part of the human knee, the anterolateral ligament (ALL). Its existence was first postulated in 1879 by a French surgeon but it has remained unseen until now. The researchers examined 41 cadavers and found the ALL in all but one. The discovery could help treat knee injuries common among athletes.

Gaia to map our Galaxy

The European Space Agency is sending the world's largest digital camera into space. It is mounted on the Gaia observatory, which was scheduled for launch between 20 December and January 2014, and will produce an accurate 3D map over five years. It's hoped it will discover thousands of planets, stars and supernovae and will enable astronomers to learn more about the evolution of our Galaxy.



The Gaia space observatory will make a 3D map of our Galaxy

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INSIDE SCIENCE

ROBERT MATTHEWS

Astrology is a load of twaddle – it's written in the stars

SHOULD WE TAKE astrology seriously? We certainly should, to judge by the huge publicity newspapers and magazines are currently giving to their pull-out guides to 'What the stars hold for you in 2014'.

Every January sees a whole new wedge of astrological predictions hit the newsstands. I doubt many readers of this magazine take them seriously. I certainly don't – but then, I am a coldly logical Virgo. Scientists generally don't have any time for astrology. The distinguished philosopher of science, Sir Karl Popper, spoke for most of them when he dismissed astrology on the grounds that it fails the acid test of any true science: it's not falsifiable. In other words, astrologers don't come up with clear-cut predictions that can be checked against reality.

Sir Karl was right – but only up to a point. Many astrological predictions are indeed very vague, like 'You may feel unappreciated this week' (who doesn't?). But to be fair, not all astrological predictions are vague; some are pretty specific. And it's these that show the real reason why astrology is twaddle: it's because its predictions consistently suck. Don't take my word for it: do a bit of scientific testing yourself. Go on to Google and find out what predictions astrologers were making for you last year, and compare them to reality. Here's what one newspaper astrologer forecast for me: 'You're celebrating by 23 June, but work doesn't let up until 13 July.' Six months on, and I'm still waiting for anything to celebrate, let alone work to let up.

Many 'serious' astrologers try to dodge such gripes by rejecting the New Year predictions as populist nonsense. They focus instead on so-called natal charts, using them to get insights into a person's personality based on the location of the planets at the time of birth. But again, the problem is not the lack of falsifiable predictions; it's that the predictions suck. Scientific studies have repeatedly shown these natal charts to be no better than guesswork.

So why does astrology remain so popular, with polls suggesting around one in four people take it seriously? I suspect it's something to do with the ancient belief that our lives are in the grip of cosmic forces. For some, these may take the form of gods; others prefer more abstract ideas. Whatever; it's this that really drives me nuts about astrology. The truth is that our lives are indeed in the grip of cosmic influences – it's just that they're far more significant than the footling trivia of astrology.

"Our lives are indeed in the grip of cosmic influences – they're just far more significant than the trivia of astrology"

Science leaves fortune tellers out in the cold – but they could be on to something when it comes to the position of the planets predicting ice ages



The influence of the Sun and Moon on the Earth have been recognised for millennia, through the ebb and flow of the tides. But during the 19th Century, astronomers started to suspect that the planets were exerting more dramatic influences on our planet. In the 1920s, the Serbian astronomer Milutin Milanković showed how the planets could affect our climate by their gravitational effect on the Earth's orbit. It's now widely accepted that the resulting changes in the intensity of solar heating triggers ice ages.

Further links between the planets and life on Earth are emerging. The journal *Astronomy And Astrophysics* recently published evidence linking the orbits of the planets to cycles of solar activity. The latter has already been implicated in events like the Little Ice Age, which caused famines between the 14th and 19th centuries. If confirmed, it would imply that the resulting social turmoil was linked to the location of the planets.

So there really is some truth in the 'astrological' idea of cosmic influence. It's just a shame it's been hijacked to peddle piffle about what we'll feel like next week. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham



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HELEN CZERSKI

Spend some time on a boat and you'll get acquainted with weird gravity

WHEN I WOKE up this morning, gravity was misbehaving. It was a disconcerting way to start the day. We take gravity completely for granted, and you can see why it took so long for humanity to 'discover' it. Of course things fall vertically downwards when you drop them. But when I dropped my hairbrush this morning, it landed somewhere off to the left. When I knelt down to pick it up, I had to hold on to the sink to stop myself falling over to the right. The shampoo bottle in the shower was rolling around all by itself, and even having a shower had been tricky. I had to chase the flow of water around because it kept falling in different directions.

None of this is unusual for me at the moment - I'm on a research ship in the middle of the north Atlantic Ocean. But living on a rolling ship really makes you think about how much we all just assume that the tug of our planet is constant, and how much we rely on it.

We're not rolling that much at the moment, and if you hung a string with a weight on it from the centre of a clock it would be swaying between the 5 and the 7. Gravity is changing direction relative to the ship. Last night was a bumpy night, and I got up in a panic around 2am to go and see whether a particular bit of experimental equipment was still on the bench I'd left it on. Can you imagine living your life not knowing what gravity might be up to tomorrow? We cope at sea by strapping everything down

with Velcro, string, tape and any other harness we can invent, just to stop it falling. And all that is only because of the change in direction. As the ship rises and falls with the waves, the effective strength of gravity is also

changing. Doing sit-ups in the ship's gym is endlessly entertaining on the roughest days. They can be almost effortless when the ship is on its way down, but might be 50 per cent harder than normal on the way back up.

One of the most important things that gravity does is make friction useful. You only get friction between two objects if they're pressed together, and that gives you some 'grip'. You need gravity to walk because that's what pushes your feet against the floor, giving you the grip to propel yourself forward. You don't have to carry a tray perfectly horizontally because gravity is pulling the teacups against the tray hard enough for



Gravity likes to make a meal of your time on a boat

“Living on a rolling ship really makes you think about how much we all assume that the tug of our planet is constant”

the friction to stop them slipping sideways, if the tilt is only small. If the tilt is bigger, this friction might not be enough (we discover that limit at dinner, when plates sometimes suddenly embark on a visit to the person sitting in the next chair).

I love being rocked to sleep, and I like the unpredictability of living temporarily in a world with weird gravity. When I'm back on shore, it'll be a few days before I take fixed stable gravity for granted again. It's one of the most fundamental consequences of living on Earth, and it's easy to ignore it. Next time you take a step, leave something unattended on a table, fill a mug right up to the top or catch a ball, just remember: there's a massive planet sitting just below you, permanently tugging hard enough to make it all possible. Gravity is doing its best to take us all on a journey to the centre of the Earth.

Just in case you're wondering, no, I don't get seasick. Those who do suffer get used to the movement of the ship within a few days, and are fine after that. Humans are amazingly adaptable! ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter who appears regularly on *Dara O Briain's Science Club*



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INTO THE FUTURE

STEPHEN BAXTER

Love snow? You'll be better off visiting another planet

DURING THE FESTIVE season many of us will be dreaming of a White Christmas. In fact the records show that we're a lot more likely to see rain in most locations on the big day than snow. But what about other planets? Will future colonists on Mars or Venus ever see Christmas snow? In fact we do have observational evidence of rain and snow on other worlds, but not of water or water-ice.

On Earth, rain occurs when warm air rises and cools, and water vapour suspended in the atmosphere condenses out into fine droplets that accumulate until they are heavy enough to fall out of the air. The formation of snow is broadly similar, save that solid ice crystals condense out rather than liquid drops. On other worlds, the same kind of processes can occur, but with different atmospheric components, and at different temperatures.

Saturn's moon Titan has a chilly surface temperature of about 180°C below freezing. The Cassini space probe and Huygens lander observed a rain of methane falling from the thick nitrogen atmosphere, feeding lakes and river systems. Some scientists have predicted methane snow on Titan's higher ground.

Where Titan is cold, the planet Venus is hot, with a massive atmosphere of mostly carbon dioxide blanketing a landscape at temperatures of over 450°C. Space probes and Earth-based observations have confirmed that acid rain falls from clouds of sulphuric acid some 50km high. If you're spending Christmas on Venus, don't pack an acid-proof brolly, however, as the rain evaporates 25km above the ground. Meanwhile, a peculiar, highly reflective deposit observed on Venus's mountain peaks by the Magellan space probe may be snow fields of an exotic substance like lead sulphide, or even tellurium.

A very exotic kind of rain has been deduced even on Jupiter, the largest planet. In 1995 the Galileo space probe observed a puzzling lack of neon in the gas giant's upper air. In 2010 scientists at the University of California, Berkeley, suggested that the neon is being leeched out by a rain of liquid helium, condensing out of high hydrogen clouds.

Even that seems almost mundane compared to what we might find on some of the 'exoplanets', the worlds of other stars discovered telescopically in the last few years. How about a snow of solid rock? A world called COROT-7b, discovered in 2009, orbits less than three million kilometres from its parent star – that compares to Mercury's distance from the Sun of about 60 million kilometres. The star-facing side, at a temperature of over



For future astronauts Mars would be the place to go to enjoy a white Christmas

“Scientists predict pebble-like ‘snow flakes’ condensing out of an atmosphere of rock vapour”

2,300°C, is hot enough to vaporise silicate rock. Scientists from Washington University, studying these results, predict pebble-like ‘snow flakes’ condensing out of an atmosphere of rock vapour.

But if you like snow, Mars is the place to go. In the Red Planet's ferocious winters, Earth-like water-ice snow has been observed to fall by NASA's Phoenix lander. But this is only a trace compared to the huge blankets of solid carbon dioxide – dry ice – that gather at the winter pole. Observations made in 2006–7 by NASA's Mars Reconnaissance Orbiter confirmed that at least some of this falls as snow (as opposed to just condensing out at the surface like frost). From the ground it would look like a blizzard, depositing a metres-thick layer of convincing-looking snow.

Of course Martian years are twice as long as our years, and 25 December won't always fall in the middle of a Martian winter. So if you want a guaranteed White Christmas, make sure you get the dates right and go visit Mars – and pack a snow shovel and a decent overcoat. ■

STEPHEN BAXTER is a science fiction writer and author of the *Northland* series. His latest novel is *Proxima* published by Gollancz

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FOCUS
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WHY DO WE

EAT TOO MUCH



ILLUSTRATOR: CHRIS-STOCKER.CO.UK



An episode of the new series of *Horizon* on BBC Two examines overeating in January



EAT CHE?

The amount we eat will ramp up this festive season, but why are we so inclined to consume more even when we're not celebrating? **Susan Aldridge** looks at the science behind expanding waistlines

SINCE MEDIEVAL TIMES the festive season has been an excuse to get down to some serious overeating. The average Briton will consume 6,000-7,000 calories on Christmas Day alone. And it's not hard to see where the excess comes from: turkey and all the trimmings, booze, Christmas pudding, mince pies, nuts and don't forget the cake, complete with marzipan and icing. It doesn't stop there – there's the office party, New Year's Eve and festive drinks with friends. That's nine days of uninterrupted consumption.

An average of 15,000 calories of food, 18,000 calories of alcohol and another 3,000 calories of snacks per person is consumed over the festive period, which is two or three times the recommended daily intake. That's according to a survey of 1,000 adults carried out last year by weight loss company Vitagetics. But why do we overeat – at Christmas and other times

too? Some answers can be found in a mountain of research in neuroscience, physiology and psychology and the latest evidence is bringing us closer to understanding the problem.

Theories on overeating abound. We may eat too much because food activates pleasure centres in the brain. Or maybe we fear waste and feel we must always clean our plates – a drive inherited from our hunter-gatherer ancestors whose lives veered between feast and famine. Some people may overindulge in an attempt to fill a psychological void created by childhood abuse, or to relieve stress.

HOW MUCH IS TOO MUCH?

With all this research, it's perhaps surprising to learn that there's actually no official definition of overeating. Government recommendations state that a man needs 2,500 calories a day to maintain his weight, a woman 2,000 calories. But





The hormone leptin (foreground) is produced by fat cells (background); levels of the hormone enable the body to regulate food consumption

→ they do not say that eating more than this is classed as overeating. “The term ‘overeating’ is loaded because it assumes that there is such a thing as normal eating. In fact our food intake fluctuates widely from day to day,” says Jeffrey Brunstrom, Professor of Experimental Psychology at the University of Bristol whose research focuses upon the role cognition plays in eating. “Maybe the best way to describe overeating is when you feel you have eaten more than you felt you should, or wanted to, and are experiencing the soporific effect

healthy weight increases the risk of diabetes, heart disease and several forms of cancer. Obesity also impairs self-confidence, body image and relationships. There is also the psychological trauma associated with eating disorders such as binge eating (consuming 2,000 to 3,000 calories at a single meal) and bulimia.

At its simplest, the body can be likened to a car. It needs to fill up with fuel regularly to keep going. Sensations of hunger and satiety act like a fuel gauge, regulating our feeding behaviour and involve various hormonal signals passing from stomach to brain. Appetite is stimulated when the stomach is empty

and releases a hormone called ghrelin into the bloodstream, while fatty tissues decrease production of the hormones leptin and insulin. These signals are transmitted to the lateral hypothalamus, a region of the brain involved in feeding and other motivated behaviours, generating the sensation of hunger.

Eating ceases under the influence of several satiety signals. When the tummy is full, a signal is sent via the vagus nerve, which has many endings in the wall of the stomach. The signal goes up to neurones in the medulla at the base of the brain, signalling that it is time to stop feeding. If you eat slowly, and with attention, this

902

The amount of calories per 100g in animal fats - the highest calorie density of any food.

that comes from eating large amounts at Christmas.”

There are cultural differences too. Cornell University food psychologist Dr Brian Wansink notes that an American will tend to eat till they are full, while those in other cultures may stop when they are no longer hungry. People in Okinawa, Japan, even have an expression for when to stop: *hara hachi bu* means eating till you are just 80 per cent full.

Whatever the cause, the consequences of overeating can be serious. Although the relationship between overeating and obesity is complex, not keeping to a

Dr Brian Wansink's weekly shop shows he practises what he preaches...



satiety signal is likely to come through louder and stronger than if you wolf down your food, or chat while you are eating, when it is more easily overridden.

But humans are more complicated than cars – they are actively motivated to carry out survival behaviours, such as eating and sex, because they give pleasure. The smell, taste, texture and sight of food can all give pleasure. Research has shown that dopamine is released in the reward centres of the brain when palatable foods are consumed. Clearly, some foods are more palatable than others.

Palatability in foods tends to boil down to the same three factors, however – fat,

“Dopamine, which is involved in our enjoyment of food, is also involved in addiction to drugs, including alcohol and tobacco”

salt and sugar. This makes sense in evolutionary terms. Fat gave our hunter-gatherer ancestors the reserves to survive winter food shortages, salt helped them avoid dehydration by retaining water, while a liking for sugar was a way of distinguishing sweet, nutritious fruits from sour, poisonous ones. In modern times, these three basic food cravings have reappeared in our favourite indulgent foods, which Wansink calls the four Cs – cookies, candy, chips and cake. Or ‘biscuits, sweets, crisps and cake’, if you live on this side of the Atlantic.

ADDICTED TO FOOD

Dopamine, which is involved in our enjoyment of food, is also involved in addiction to drugs, including alcohol and tobacco, so it could be that it is equally possible to become addicted to foods, especially those high in sugar and fat. In such cases, overeating is easy to understand. A report from the long-running Nurses' Health Study found that women who had suffered childhood abuse were twice as likely to show addiction-like eating behaviours. In another study, David Ludwig, of Boston Children's Hospital, used functional magnetic resonance imaging to observe brain activity during

the four-hour period after a meal had been consumed. Volunteers consumed milkshakes with the same calories, sweetness and taste – except that one contained fast-acting or ‘high glycaemic index’ (high GI) carbohydrates, while the other had slower-acting or ‘lower glycaemic index’ (low GI) carbohydrates. As is well known, consuming high GI foods leads to a rapid rise in blood glucose, followed by a sharp crash. The brain scan revealed this crash to be linked to intense hunger and strong activation of the nucleus accumbens, a region of the brain involved in addictive behaviour, reward and craving. The researchers

suggest that limiting high GI foods may be one way of controlling the urge to overeat.

Meanwhile, research by Garret Stuber and his team at the University of North Carolina has shown that at least one specific neural circuit drives overeating – at least in mice. When this circuit is triggered, he believes animals eat because they enjoy it rather than because they are hungry (see ‘How overeating is hardwired in the brain, below’).

Meanwhile in Bristol, Prof Brunstrom is working on a different approach to understanding overeating. His research suggests that planning what to eat before a meal may be as important as



OVEREATING IS HARDWIRED IN THE BRAIN

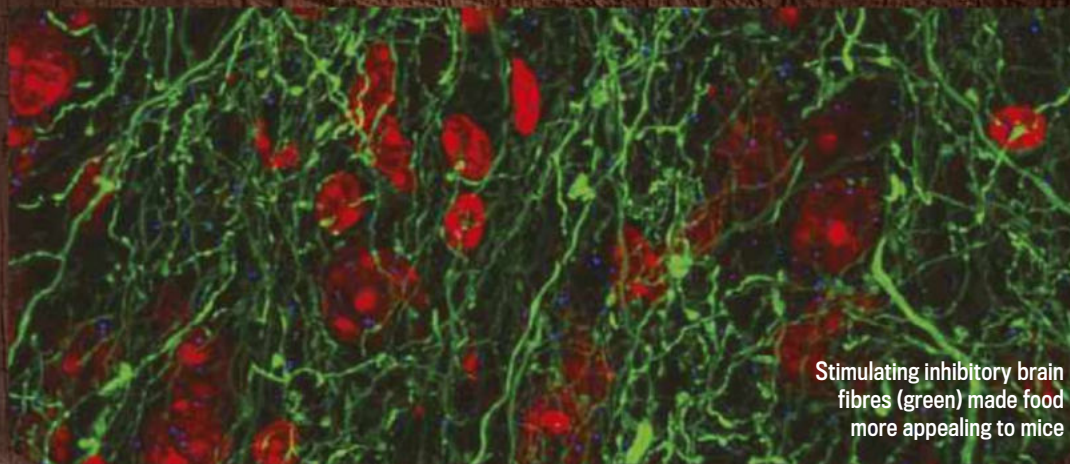
Dr Garret Stuber of the University of North Carolina School of Medicine has found a pathway in the brain that makes animals eat, even when they're not hungry

“The lateral hypothalamus (LH) is a part of the brain that is involved in motivational behaviours, including feeding. It's long been known that stimulating the LH will cause a mouse to overeat. But it remained a mystery as to which particular neurones were involved, which is where we came in. We'd noted that so-called GABA neurones close by, in another region, had very dense projections into the LH, so we decided to investigate this. This region is actually an outcropping of the amygdala, which is involved in emotion, and forms a bridge to the LH.

We used a technique called optogenetics, where we genetically modified the GABA neurones we were interested in so they could be stimulated by an optic fibre implanted into the brain. In this way, we could turn the circuit on and off to see what happened to the behaviour of the mice in the experiment. They started to eat within

seconds of the circuit being stimulated and continued to eat, even though they couldn't be hungry, until we turned the circuit off. When the circuit was off, they showed no interest in food – even if they were hungry. Stimulating this circuit increases the palatability of food, rather than satisfying hunger, because the LH is also involved in behaviour that leads to a reward.

This same brain pathway is very likely to exist in humans because this is a region of the brain that's been well conserved during evolution. So we're now trying to set up studies to see if this behaviour is replicated in humans. Our studies underscore the fact that overeating has a strong neurobiological basis and the role of brain circuitry is very significant. This brain pathway may play a role in food consumption and eating disorders, such as binge eating, and further research may help us work out how to modify it and develop treatments.



Stimulating inhibitory brain fibres (green) made food more appealing to mice



Not feeling hungry? Tests reveal that you'll still plough through five-day-old, stale popcorn

→ the satiety signals generated during the meal itself, even if we are not always conscious of this forward thinking. His team has developed ways of measuring the expected satiety (ES) of different foods – that is, the extent to which we perceive a food as able to stave off hunger.

“There is a large mismatch between how many calories a food contains and how filling it is perceived to be,” he says. “For instance, potatoes have a higher ES than chocolate. Very energy dense foods like chocolate are perceived to deliver less reduction in hunger.” Decisions on ES seem to be influenced by volume, with higher volume, less energy-dense foods seen as more satisfying.

It is possible to manipulate a food for ES by altering its viscosity. Drinks tend to have a low ES but are often loaded with calories, so their unthinking consumption has been linked to weight gain. On the other hand, increasing viscosity and creamy texture increased the ES value of a yoghurt drink. This could be one way of reducing the amount of energy-containing drinks consumed.

How much people eat is also influenced by factors such as the size of the packet, plate and portion, the variety of food available and the context in which it is eaten. This is well illustrated by one of Wansink's experiments which shows that people will eat, even if they are not

hungry and the food is not palatable. His team invited unsuspecting volunteers to a movie, offering free popcorn in return for answering a questionnaire. The popcorn was five days old and tasted stale. Most of the volunteers had already lunched, so they were not hungry. Yet they still ate the stale popcorn. Some were given medium-size buckets, others large-size buckets. Those given the latter ate more (173 calories more, equivalent to 21 more dips in their bucket), even though they hotly denied being influenced by the size of the container when questioned afterwards. Wansink has run many other popcorn studies and the findings are the same – people eat more from a larger container.

SIZE MATTERS

The size issue is worth looking at in more detail. Between 1970 and 2000, the number of large sizes of food products in supermarkets increased tenfold. The spread of fast food outlets has led to the proliferation of super-size and jumbo-size

“There is a large mismatch between how many calories a food contains and how filling it is perceived to be”

CURB YOUR OVEREATING... WITH AN IMPLANT

A new pacemaker for the stomach could be the key to helping people who are unable to control their food consumption

THE VAGUS NERVE helps regulate sensations of hunger, satisfaction and how full you feel. Surgical vagotomy, which involves cutting the vagus nerve near the stomach, was used historically as a treatment for stomach ulcers. Patients often experienced weight loss and reduced appetite as side effects. The Minnesota-based company EnteroMedics used these findings as a basis for designing its VBLOC therapy, which intermittently blocks vagus nerve signals between the brain and the stomach with a pacemaker-like device called the Maestro System. This is implanted and programmed by minimally invasive surgery and has been safely used in over 600 patients in clinical trials, producing significant weight loss.

Existing treatments for obesity – namely, diet and exercise, medication

and weight-loss surgery – all have their drawbacks. EnteroMedics believes that VBLOC therapy can fill the gap and offer new hope for the 20 million obese people who would currently qualify for surgery because of their weight and complications like diabetes or high blood pressure.



This little device can put a reign on the vagus nerve and your appetite

portions as chains compete in the ‘value for money’ stakes. In a famous study carried out by University of Pennsylvania psychologist Paul Rozin and the French sociologist Claude Fischler in 2003, portion sizes were compared in fast food outlets, pizzerias, ice cream parlours and restaurants in the cities of Philadelphia and Paris. Of 36 meals and beverages compared, 26 had a significantly lower mass in Paris, with portions being an average of 25 per cent heavier in the American city.

To illustrate the point, Wansink invited 85 nutrition professors and graduate students to an ice cream party. On arrival, they were given either a medium or large bowl and either a medium or large ice cream scoop and told to help themselves. Those given large bowls and scoops served themselves with 53 per cent more ice cream than those with small bowls and small scoops.

Studies have shown that a wide variety of food choices at a meal will mean that you consume more



This tendency to eat more from a large portion is likely because you can consume a lot of food before you see much difference in the portion size. The 'clean plate' perhaps gives the eater a goal, which acts as a clear signal to finish eating – only you have to do more eating to achieve this with a big portion.

VARIETY IS THE SPICE OF LIFE

Another important factor in overeating is variety. Brunstrom has carried out experiments that show how variety increases the amount of food consumed. Participants were shown images of four dishes – chicken tikka masala, spaghetti bolognese, apricot slice and lemon tart

– in various combinations on a computer, and asked to manipulate the image of the second course to show how much they would serve themselves. When there was variety – when sweet followed savoury – the volunteers rated the foods as more pleasant and said they would select a bigger helping.

Meanwhile, as you head towards the office Christmas lunch or New Year's dinner, bear in mind that psychology professor John de Castro of Georgia State University has figured out that you eat 35 per cent more if you eat with one other person than if you eat alone. If you eat with a group of seven or more, you consume nearly twice as much. This is because chatting distracts us from the food and we stop monitoring what goes into our mouths. On the other hand, speedy eating also tends to lead to overconsumption. Many studies have shown that it takes 20 minutes for the brain to act on satiety signals from the body, which is plenty of time for a second slice of pizza or a return visit to the buffet.

However, there are many tricks for thwarting the conspiracy between the brain and the environment which seems to promote overeating. For instance, at the festive buffet, put your plate down when you are chatting and put only two items on your plate at each trip to the food table. If you are shopping for crockery in the January sales, buy some smaller plates for dinner. In a restaurant, you could opt for two starters and skip the main, or maybe share a pizza or a dessert. Wansink also

£5,000,000,000

The cost to the NHS every year due to problems related to patients being overweight or obese

(Source: Department of Health)

describes the 'pause point', and recommends creating interruptions in your eating – by choosing individually wrapped biscuits, sweets or chocolates, or by moving dishes of food out of easy reach. Finally, be mindful in your eating – ignore distractions, focus on the food and eat it slowly.

The general tendency to 'clean the plate' and eat whenever the opportunity arises seems to imply an inherent greediness in human nature. Maybe it is a throwback to our hunter-gatherer past, when people never knew when they would eat again? In those days, this behaviour had a clear survival value. In 21st Century Britain, the opposite is probably true. ■

BRITAIN'S EXPANDING WAISTLINE



61.3 per cent of adults are overweight or obese in the UK (source: Gov.uk)

Find out more

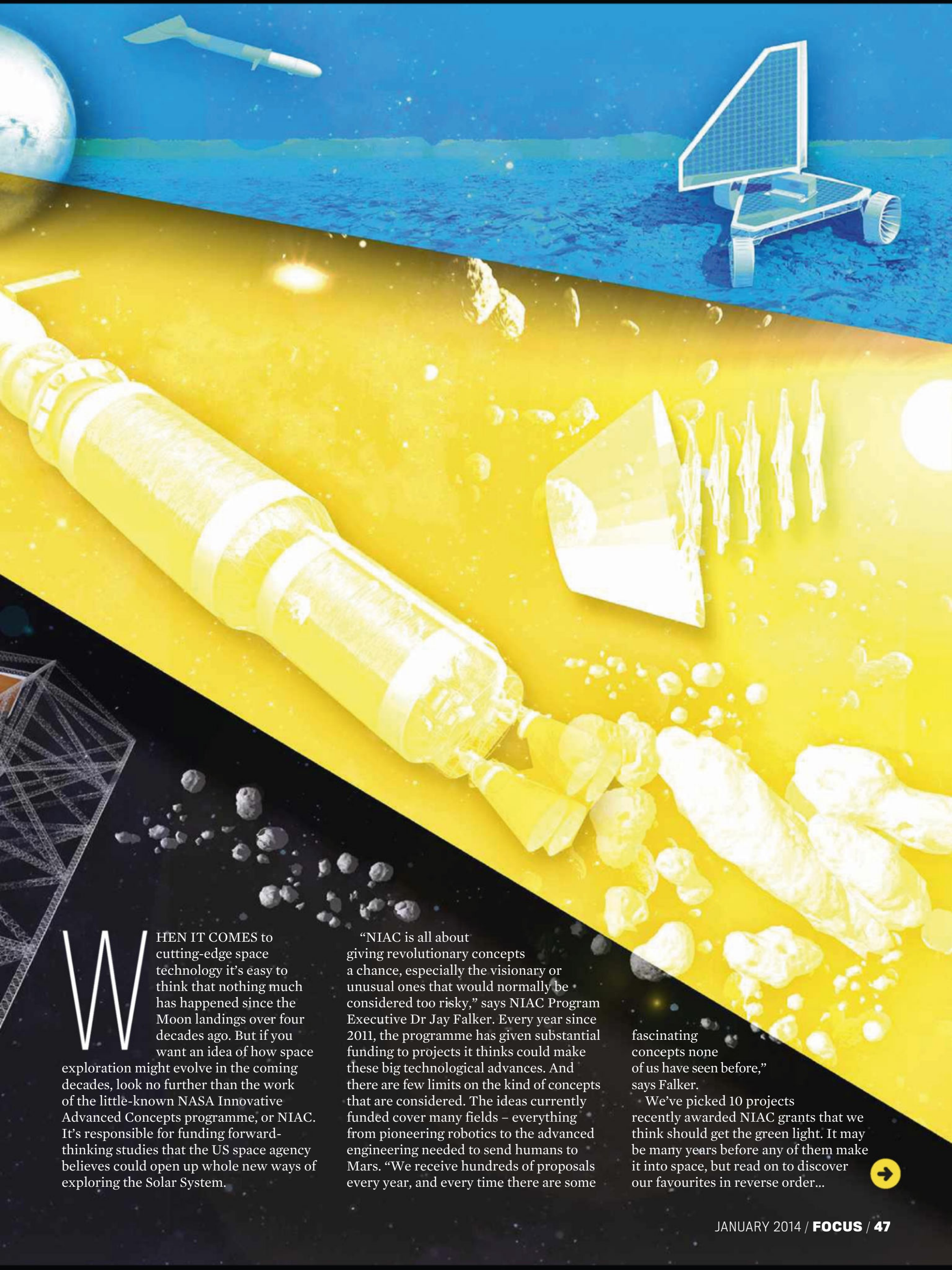


Listen to *Constant Cravings: Does Food Addiction Exist?* on overeating and addiction <http://bbc.in/15Kkm4U>

SUSAN ALDRIDGE is a science writer and former medical researcher

NASA'S CRAZIEST IDEAS

They may sound mad but these pioneering projects will change the very nature of space exploration as we know it. **WILL GATER** is go for launch...



WHEN IT COMES to cutting-edge space technology it's easy to think that nothing much has happened since the Moon landings over four decades ago. But if you want an idea of how space exploration might evolve in the coming decades, look no further than the work of the little-known NASA Innovative Advanced Concepts programme, or NIAC. It's responsible for funding forward-thinking studies that the US space agency believes could open up whole new ways of exploring the Solar System.

"NIAC is all about giving revolutionary concepts a chance, especially the visionary or unusual ones that would normally be considered too risky," says NIAC Program Executive Dr Jay Falker. Every year since 2011, the programme has given substantial funding to projects it thinks could make these big technological advances. And there are few limits on the kind of concepts that are considered. The ideas currently funded cover many fields – everything from pioneering robotics to the advanced engineering needed to send humans to Mars. "We receive hundreds of proposals every year, and every time there are some

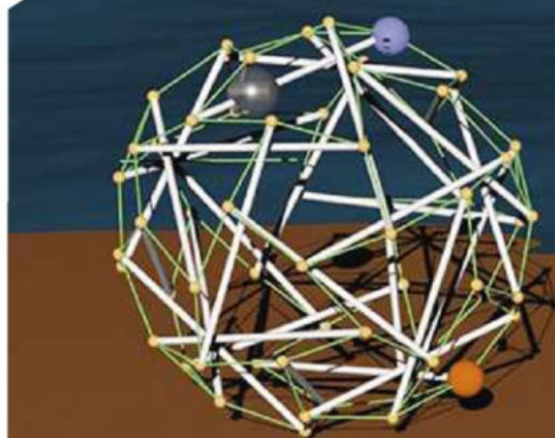
fascinating concepts none of us have seen before," says Falker.

We've picked 10 projects recently awarded NIAC grants that we think should get the green light. It may be many years before any of them make it into space, but read on to discover our favourites in reverse order...



10 SPRINGY ROVERS

ROCKETS, PARACHUTES AND airbags have helped land several rovers on Mars, but the next generation of robotic planetary explorers may use a totally new technology. Dr Vytas SunSpiral and his colleagues at NASA are looking to send a robot to Saturn's moon Titan that will be constructed entirely of a set of rods held in place by cables under tension. This 'tensegrity structure' would be equipped with scientific instruments and wouldn't need a parachute or airbag. "The structure itself is compliant and can absorb strong impact shocks, so it can land safely while protecting a payload," explains SunSpiral. Not only that but it will be mobile too, he says. "Once landed, it can shorten and lengthen its cables to induce rolling and explore the planet."



Sensors could be bounced on to a planet by a springy ball-like structure

9 ASTRONAUT HIBERNATION

THE CONCEPT OF putting astronauts into hibernation during a long mission into interplanetary space is ever-present in science-fiction. From *Avatar* to *2001: A Space Odyssey*, complex life-support systems have become a visual synonym for the advanced space technology of the future. Now, as we look to Mars as a place to explore, there are some who are working to make the science fiction of hibernating astronauts a reality. Dr John E Bradford is president of SpaceWorks Engineering, a US-based company that was awarded funds to investigate the pioneering technology. "In short, we are attempting to put a Mars-bound crew in a deep-sleep stasis during the six to nine-month transfer periods between Earth and Mars," he explains.

The 'deep-sleep' method the SpaceWorks team is investigating is known as hypothermia therapy. "It's used regularly to treat traumatic injuries," says Bradford. "Inducing this torpor state requires reducing the core body temperature by 5 to 10°F [up to 6°C] and providing some mild sedatives." It's a very different process to the 'freezing' of astronauts often seen on the big screen, says Bradford. "We're not attempting 'cryo-preservation' and the cessation of all molecular activity. Our goal is to be able to keep the crew in an inactive state and limited to a confined space during certain parts of the mission."

To keep the astronauts alive the team envisage using technology that's already in use in medicine. "They will be fed and hydrated through an intravenous line using an aqueous solution called 'total parenteral nutrition' or TPN. This method of providing sustenance for humans is routinely used for extended durations with cancer patients," says Bradford.

There are several benefits to be had from having a crew sleep their way through a long space voyage, argues Bradford. "With the crew in this state, we believe we can reduce the mass and volume of the in-space habitat significantly. This ultimately reduces the entire launch mass. The habitat itself will be a very small module containing four to six crew members, each in their own sleep chamber. By contrast, a typical habitat for an active

"Imagine going to sleep and waking up on Mars six months later, no worse for wear!"

Dr John E Bradford, president of SpaceWorks Engineering

crew is required to have space for food preparation and eating, exercise, science stations, bathrooms, sleeping quarters and entertainment."

It may even be better for the astronauts' well-being. "On a Mars mission, you can expect to have a small group of people confined to a very small space for an extended period of time, under a lot of stress and with no way to abort if there's a problem," explains Bradford. "A lot of these issues are solved if the crew is asleep during peak periods of stress and likely boredom."

Nevertheless, there's still much more research to be done before the technology makes it into space. "Ultimately, I think it will be the preferred way to travel," says Bradford. "Just imagine going to sleep and waking up on Mars six months later, no worse for wear!"

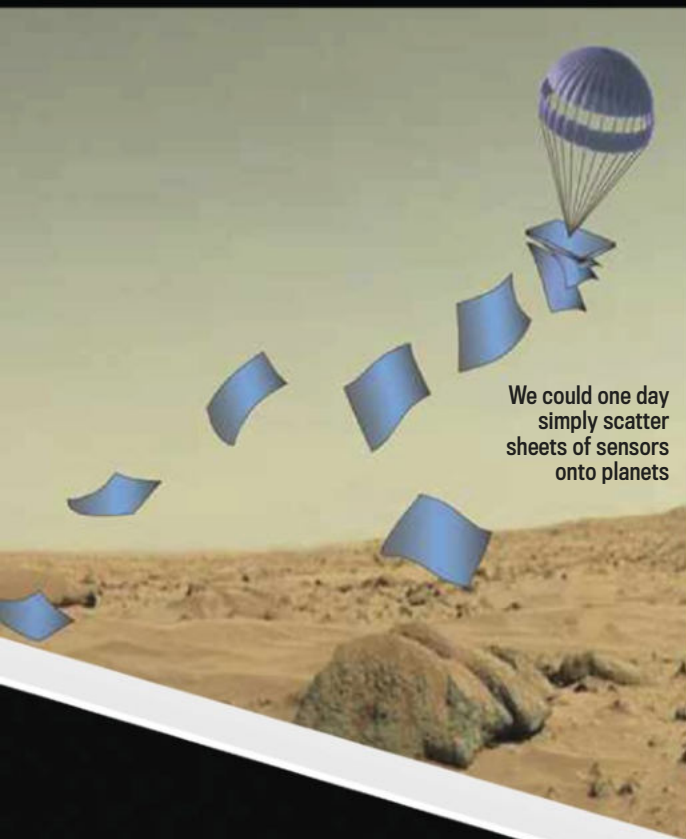
To make the trip to the Red Planet a more comfortable experience, future explorers may have to be put into a state of suspended animation

8 OFF-PLANET 3D PRINTING

THE FIRST ASTRONAUTS to explore Mars face a dangerous mission. Apart from the radiation on the way and the landing, they'll also have to contend with living on a distant outpost with little chance of a speedy re-supply if something goes wrong. If a vital component of their spacecraft breaks on the surface, there'll be no mechanic on hand to bring them a spare. The 'Biomaterials out of thin air' NIAC project could be the solution. It's examining how living cells could be used, in conjunction with 3D-printing, to create spacecraft parts, construction materials and, potentially, even human tissue.



3D printers could be put to work building habitats on the Moon



We could one day simply scatter sheets of sensors onto planets

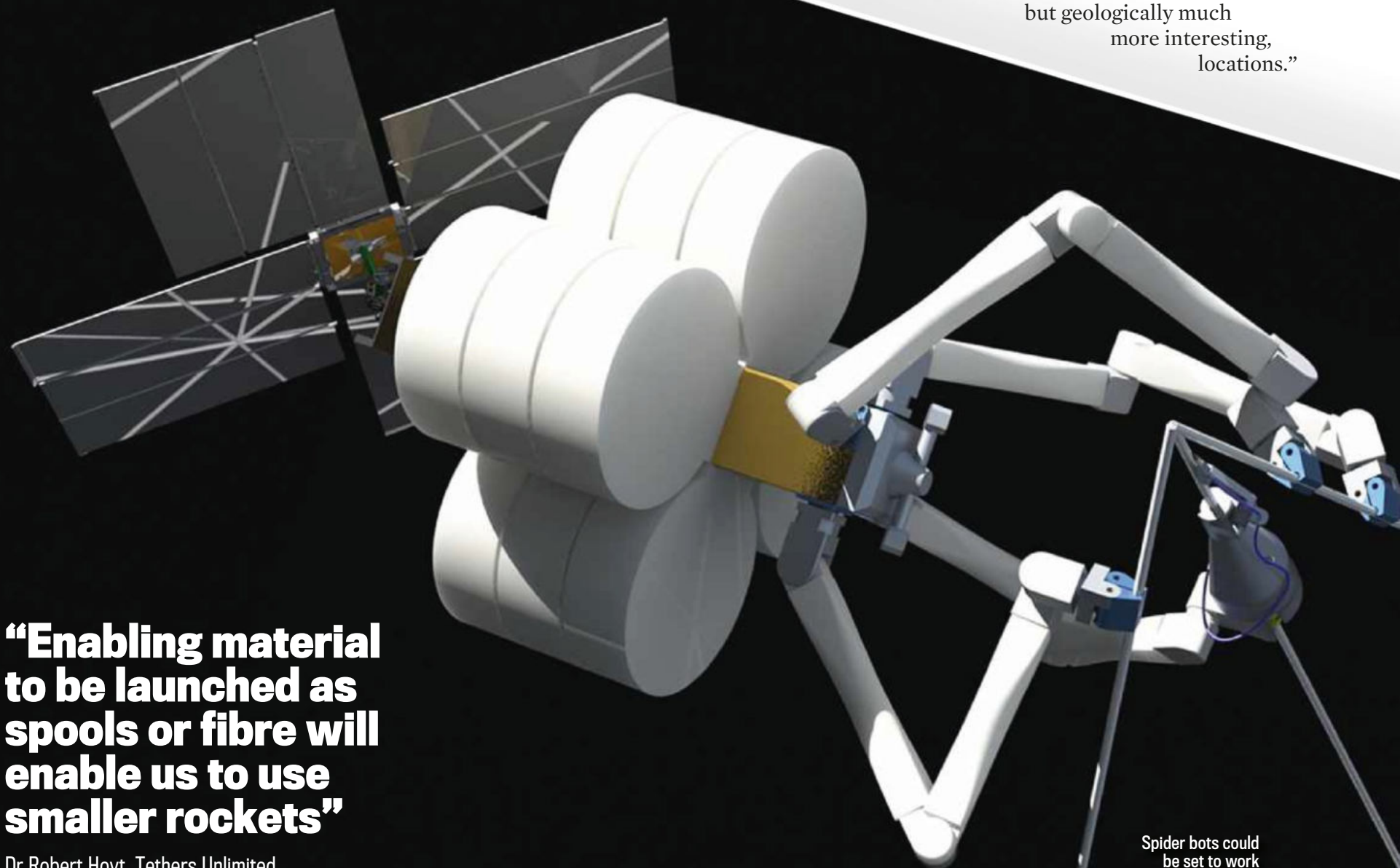
7 FLAT LANDERS

THE TENSE LANDING of NASA's Mars Science Laboratory, Curiosity, back in 2012 took years of planning and advanced engineering, and it all rested on the perfect performance of the mission's landing systems. Today, Curiosity is giving us a unique view of one of the most scientifically interesting places on the Red Planet. But there may be a much simpler

way to explore many more of these tantalising environments throughout the Solar System.

The Two-Dimensional Planetary Surface Landers project is looking into the technology needed to build numerous wafer-thin 'landers' that could be scattered onto a planet, moon or asteroid. Each lander would be only a few millimetres deep and would cover about one square metre; on-board would be solar panels and communications electronics as well as radiation, wind and temperature sensors.

They may even carry thin scientific instruments for studying their surroundings. Tens of landers would be sent to the target in one go, with the possibility of sending up to 50. "When a number of 2D landers are deployed, some may make it and others may not. It is still acceptable," says the project's lead Dr Hamid Hemmati. "It also enables landing at highly risky, but geologically much more interesting, locations."



"Enabling material to be launched as spools or fibre will enable us to use smaller rockets"

Dr Robert Hoyt, Tethers Unlimited

Spider bots could be set to work building large structures in space

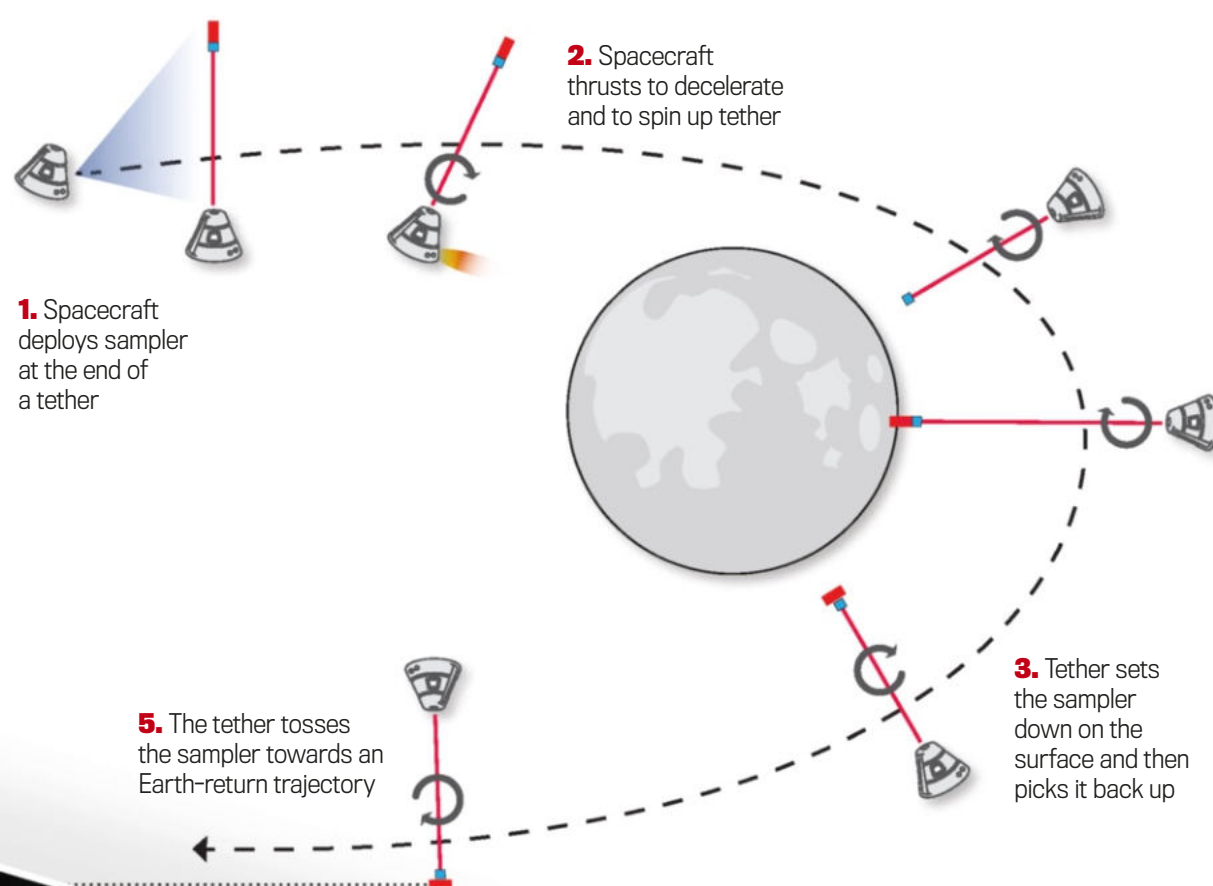
6 SMASH AND GRAB SPACECRAFT

ROBOTIC ROVERS AND orbiting spacecraft are all well and good for exploring the Solar System, but what planetary scientists everywhere dream of are samples of these distant worlds. Getting material back to Earth is not easy, though. If your probe does manage to launch without a hitch it still has to fly all the way to its destination, carry out a risky landing, take-off and then return through Earth's atmosphere in one piece. Just ask the team that worked on NASA's Genesis mission. Genesis successfully sampled the solar wind during a 32-million-km journey through space, only to embed itself at 320km/h in the Utah desert, when parachutes failed to open.

Now a team led by

Prof Robert Winglee at the University of Washington is investigating the feasibility of a planetary 'smash and grab' sample-return technique. The idea is to have a probe drop penetrators into the surface of an asteroid or a moon as it flies past. The penetrators would be attached to the spacecraft by a long tether. "For asteroids, only a few kilometres of tether are needed, and maybe a few tens of kilometres for

moons," explains Winglee. As the penetrators smash into the surface they will pick up some material in an on-board sample-return capsule. This capsule will then be reeled all the way back to the probe, using the tether, before being sent on the long trip home to Earth. "It will provide a huge step towards understanding the origins of the Solar System," says Winglee.



5 ROBOT BUILDERS IN ORBIT

SCIENCE FICTION HAS long depicted visions of vast structures looming in orbit and spaceships with huge solar arrays gliding through the Solar System. Launching such enormous structures into space is astronomically expensive though and, as we've seen with the International Space Station, you need astronauts to do much of the construction work.

One method to get around this, now being studied by Dr Robert Hoyt and his colleagues at Tethers Unlimited, is to

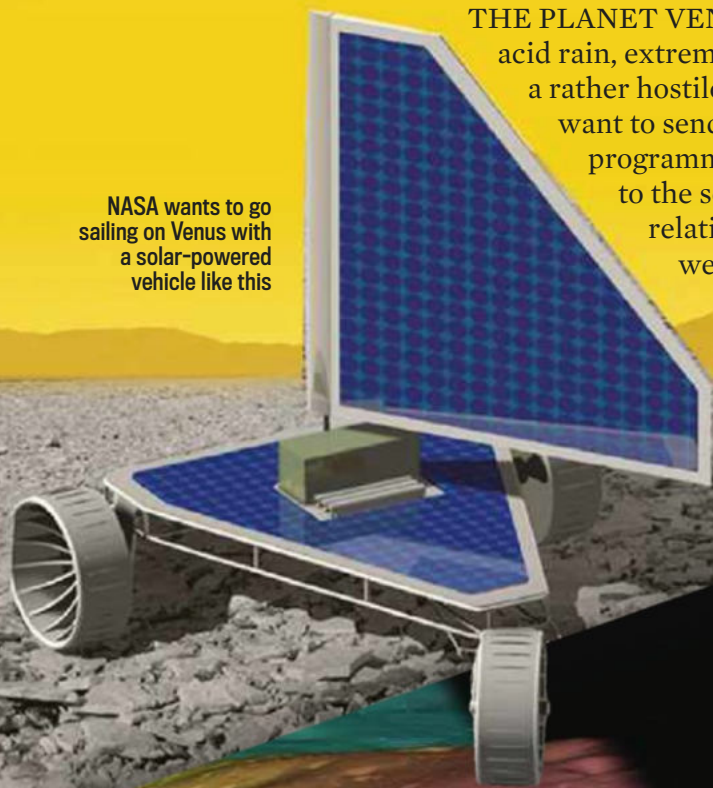
launch something that is able to construct itself once in orbit – they call their idea 'SpiderFab'. "We're developing a process where we can launch materials in the form of a spool of yarn or tape, and then process that material to create the desired structure," explains Hoyt. By blending advanced robotics with 3D printing technology, the team hopes to start making basic orbiting structures before progressing on to construct parts for the next generation of spacecraft. "Manned missions to Mars or other planetary bodies will need large structures to support solar arrays, radiation shields and other critical components," says Hoyt. "Enabling the material to be launched in a compact form, such as spools of fibre or tanks of polymer, will enable us to use smaller, less expensive rockets."



4 SAIL-POWERED ROVER

NASA wants to go sailing on Venus with a solar-powered vehicle like this

THE PLANET VENUS has a truly fearsome reputation, and a well-deserved one at that. Its sulphuric acid rain, extreme atmospheric pressure and a searing surface temperature of around 460°C make it a rather hostile place. In fact, it's probably the last place you'd think that planetary scientists would want to send a rover. But they do. And they even want to give it a sail. Yes, a sail. As part of the NIAC programme, NASA scientists are researching the practicalities of sending a 'land-sailing rover' to the second closest planet to the Sun. The rover would be swept along Venus's relatively flat lava plains by a light breeze, say the scientists. If all went well, the team reckons the rover could survive for a month or so.



Crater Shackleton's depths are revealed by a topographic view (left-hand side) courtesy of the Lunar Reconnaissance Orbiter's Laser Altimeter

3 SUNLIGHT REFLECTORS

IF HUMANS EVER return to the Moon, one of the places we'll likely visit is the region around the crater Shackleton. The crater's interior is cloaked in permanent shadow while its rim is lit up by almost constant sunlight. The soil within may contain ice that can be used by a future Moon base and the rim would be an ideal place to put solar panels. But exploring the depths of Shackleton, and features like it on other bodies, would be difficult due to the darkness. The Transformers for Extreme Environments project aims to change all that by developing lightweight, autonomous machines capable of reflecting sunlight down into the dark. The origami-like structures could be used for illuminating the crater floor, warming a patch of ground and for communications.

2 BALLOON TELESCOPE

SENDING TELESCOPES INTO orbit can be a very costly way to study the Universe. One way astronomers have got around this is by attaching telescopes to enormous helium balloons and letting them drift high up into the sky. These floating observatories can then view the cosmos largely unimpeded by the gases in our atmosphere that absorb many of the wavelengths of celestial radiation that are interesting to astronomers.

The Large Balloon Reflector (or LBR) takes this concept one step further. It will incorporate two balloons; the first 100m-wide 'carrier balloon' will take the telescope to roughly 130,000ft (39km) in altitude. Fixed inside this balloon will be a second, smaller one measuring 20m in diameter. A 10m-wide patch of this balloon will be metallised to create a mirror-like surface, which will collect light from the stars.

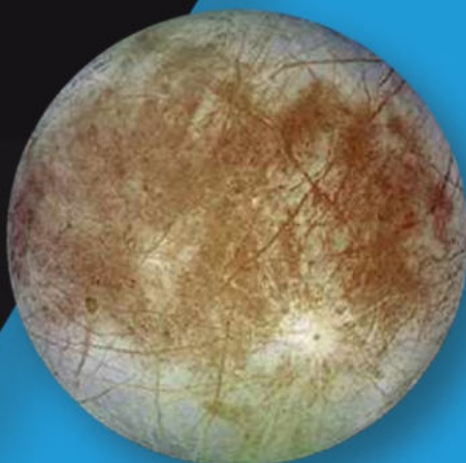
The LBR will study celestial objects at wavelengths of between 100 and 300 microns – what is known as 'terrahertz' radiation. Crucially, this radiation will pass through the balloon material largely unhindered, but not the 'mirror'. "This wavelength provides clues to

The huge 100m-wide LBR could look like this space balloon

our cosmic origins, from the Big Bang to the Earth itself," says the project's lead, Prof Christopher Walker from the University of Arizona. "The largest terrahertz/far-infrared telescope to fly was the Herschel Space Observatory. LBR will be three times larger and have about an order of magnitude greater collecting area, allowing it to probe this important wavelength deeper than ever before."

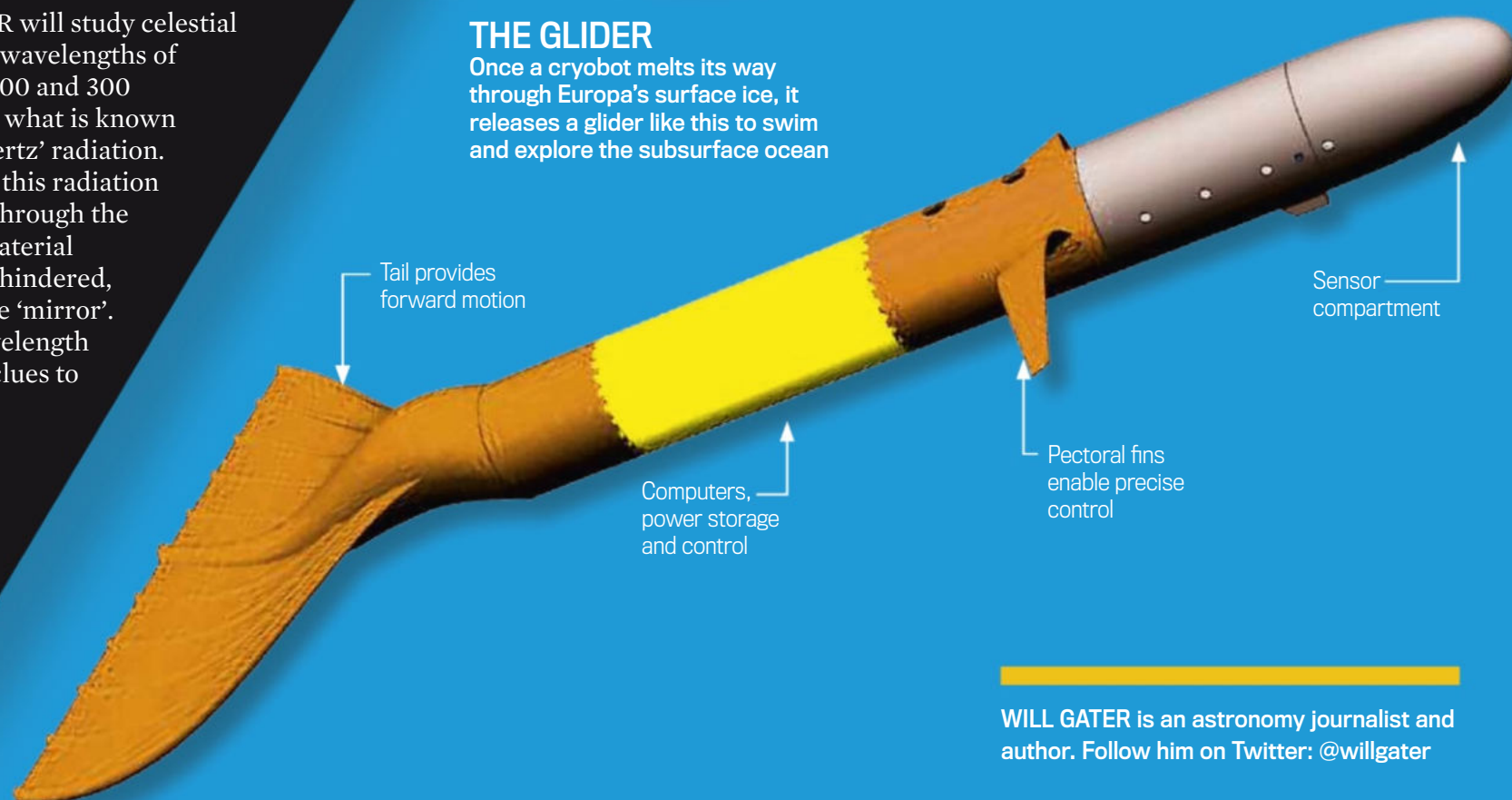
The LBR team hope to use the huge balloon-borne telescope to study objects such as stars and planets in the process of forming.

Jupiter's moon Europa has a thick ice-sheet that covers a potentially life-friendly ocean



THE GLIDER

Once a cryobot melts its way through Europa's surface ice, it releases a glider like this to swim and explore the subsurface ocean



1 ROBOT SUBMARINES

HIDDEN BENEATH THE surface of Jupiter's moon Europa is a vast ocean of liquid water. It's an astrobiologist's dream. Now a NIAC project, led by Professor Leigh McCue at Virginia Tech University, has laid out what's needed to explore it.

The team's concept involves sending three landers to the surface of Europa. Each will be equipped with a 'cryobot' that will melt its way through the icy crust before breaking out into the subsurface ocean. The three cryobots will then release 'gliders' that will swim through the ocean, studying it in detail. "Europa's ocean offers our mostly likely prospect for finding some form of extraterrestrial life within our Solar System," says McCue. "That is what is most exciting to me; under-ice exploration of Europa could change our very understanding of life."

WILL GATER is an astronomy journalist and author. Follow him on Twitter: @willgater

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THE YEAR SCIENCE WILL
BLOW YOUR MIND

2014



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WORDS



SPACE

Stuart Clark is an astronomer, journalist and the author of *The Sky's Dark Labyrinth* trilogy



BIOLOGY

Penny Sarchet is an award-winning science journalist with a PhD in plant genetics



TECHNOLOGY

David Bayon is a technology writer and a former editor of *PC Pro*



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SPACE

EUROPEAN SPACECRAFT WILL LAND ON A COMET

THE MISSION SET to dominate the space exploration agenda next year is Rosetta, the European Space Agency's comet chaser. "Rosetta will spend more than a year in close proximity to the comet, observing its rise to peak activity during the portion of its orbit that takes it closest to the Sun," says Matt Taylor, ESA Rosetta Project Scientist.

This is the riskiest mission ever launched by ESA, and it got off to a rocky start. One month before the planned January 2003 launch, an identical Ariane 5 rocket exploded during lift-off. Rather than risk the billion-Euro Rosetta mission, ESA delayed its flight while the problem was investigated. This robbed it of its intended target, Comet Wirtanen, and astronomers had to choose a second comet to visit.

In March 2003, Rosetta set off for Comet Churyumov-Gerasimenko. For the last three years, Rosetta has been in hibernation, with all but the smallest flicker of power keeping it alive. On 20 January 2014, the spacecraft will awaken itself and attempt to find Earth with its antenna. This will be a nervous waiting game for those sat on terra firma.

Once contact is re-established, the main science mission will begin. It will approach the comet in May and enter a walking-pace mapping orbit around the icy nucleus, scoping out its target. It will then study the comet looking for a landing site, before releasing a lander, called Philae, in November. Upon contact, Philae will

"This is our last best chance to study the pristine Moon before there is a lot of human activity there"

anchor itself. "Once safely harpooned on the comet, the analyses carried out have the potential to unlock 4.6-billion-year-old secrets about the origin of water and organic material in the early Solar System," says Natalie Starkey, a planetary scientist from The Open University, Milton Keynes.

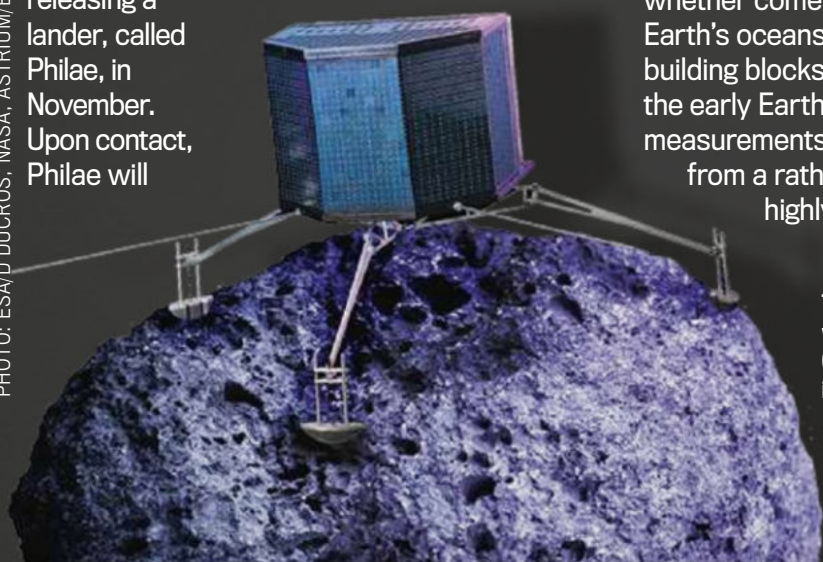
This data will help scientists decide whether comets brought the water for Earth's oceans. It could also show us which building blocks of life were incorporated into the early Earth. "It will provide the first ever measurements of the evolution of a comet, from a rather inert icy dirt ball, to a highly active comet," says Taylor.

The Rosetta lander Philae will touch down on Comet Churyumov-Gerasimenko in November

NASA WILL MAKE ITS LAST VISIT TO THE 'PRISTINE MOON'

THERE'S NO DOUBT that the Moon will be a focus in 2014. NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE - pronounced 'laddie' rather than 'lady' *Little Britain* style) is in orbit now and will complete its mission in 2014.

It is studying the tenuous atmosphere and the dust environment around the Moon. NASA Apollo astronauts reported seeing glows and rays near the rising and setting Sun that have never been explained. Yet what makes the investigation far more compelling is what NASA Ames Director Pete Worden said to the *Universe Today* website on 20 October 2013.



NASA's LADEE probe will investigate the Moon's tenuous atmosphere



He explained: "This is probably our last best chance to study the pristine Moon before there is a lot of human activity there changing things."

That is a sobering statement and reflects upon the increasing number of projects from private organisations that hope to launch rovers to the Moon. These include the Google Lunar X-Prize competitors. A prize of \$40 million is being offered for any team that lands on the Moon, traverses 500m and transmits two 'Mooncasts' back to Earth. The deadline for doing this is 31 December 2015.

LADEE is more than simply another science-gathering mission, though. It is also a test of a standard spacecraft design that could help NASA drastically reduce the cost of its small science missions.

SOLAR SAIL SPACECRAFT TO GRAZE THE SUN

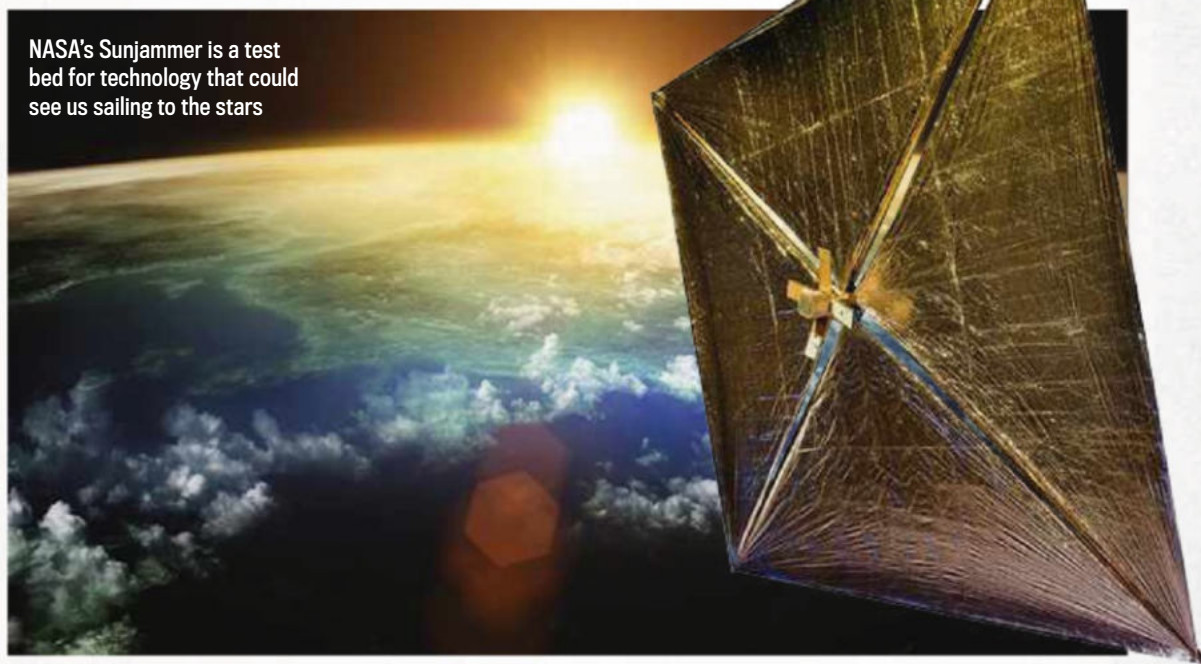
THEY DON'T HAVE engines, require no fuel and yet can journey just about anywhere in the Solar System. Solar sails harness the pressure of sunlight to push them through space.

Sunjammer is a NASA project to demonstrate the largest solar sail yet made. In 2010, the Japanese Space Agency sailed the 14x14m IKAROS mission all the way to Venus. Now, the Americans want to do it bigger and better. Sunjammer will be 38x38m when deployed in space, and at launch it will be packed into a dishwasher-sized spacecraft. Designed to demonstrate the level of control that can be achieved with a solar sail, it will perform manoeuvres that are impossible for conventional spacecraft, such as 'hovering' in space.

It is named after the 1964 Arthur C Clarke story, in which the term 'solar sailing' was coined. "Sunjammer will be the first truly operational solar sail mission, demonstrating that this exciting technology can enable entirely new types of orbits with compelling applications for space weather," says Colin McInnes, University of Strathclyde, Glasgow.

Sunjammer will carry a pair of instruments to monitor the Sun and warn us of solar flares, which contribute to the space weather that disrupts communications on Earth. Because it sails on starlight, it will be able to go closer to the Sun than other conventional spacecraft. With this first flight, Sunjammer will fly 3 million km away from the Earth and provide twice the warning time achieved with NASA's current solar watchdog, the Advanced Composition Explorer. Eventually a flotilla of solar sails could monitor the Sun from all angles at all times.

NASA's Sunjammer is a test bed for technology that could see us sailing to the stars



INVASION OF MARS

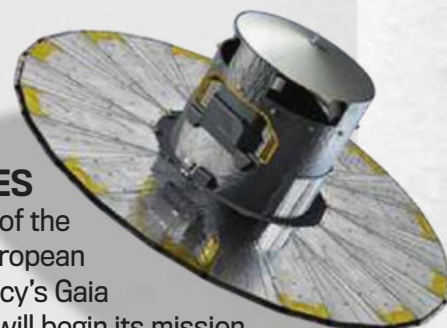
NASA'S CURIOSITY MARS rover set out on 4 July 2013 towards its ultimate goal: Mount Sharp. The strata of the mountain will allow scientists to study the climate history of the Red Planet. When it arrives in summer 2014 it will investigate how long the Martian surface had water; the longer the better for the possibility of life.

By September, Curiosity could have some new neighbours in the shape of India's Mars Orbiter Mission and NASA's Mars Atmosphere and Volatile Evolution probe. They will be analysing Mars's atmosphere to better understand its history, including the sequence of events that caused it to lose its atmosphere.

JANUARY 2014

GAIA LAUNCHES

At the start of the year, the European Space Agency's Gaia spacecraft will begin its mission to map 1 billion stars, creating the largest star map ever (see p28).



BIOLOGY

FIRST PATIENTS TO RECEIVE STEM CELL TRANSPLANTS

BY THE END of August, patients will have started going under the knife in the world's first clinical trial of stem cell-based organ transplants, funded by the UK's Medical Research Council. The trial will involve patients who have suffered damage to their voice box and have difficulty breathing, speaking, and swallowing. This can often be the case after surgery when a patient has required help breathing. Martin Birchall and his colleagues have already used patients' own stem cells to save the lives of two seriously ill patients, but now they want to make the technology a routine treatment.

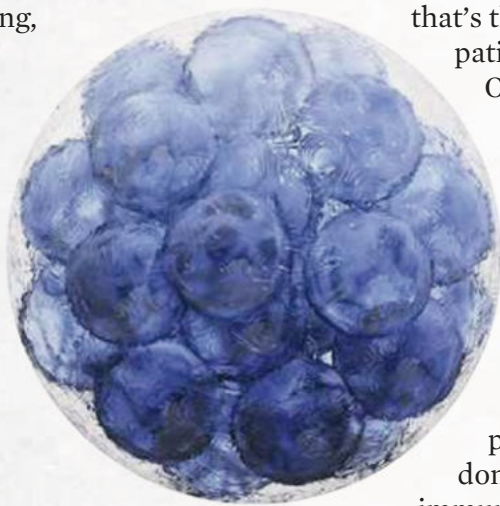
To grow the transplant tissue, the stem cells will first be taken from the hip of the patient, and then brought back to the laboratory to be grown and expanded. Chemical signals are then used to transform the

cells into cartilage, before being grafted onto a scaffold that has been made by stripping away the cells from the organ of a conventional transplant donor.

The team already has a store of donor scaffolds. "We have a range of transplant donors and then we defrost the one that's the right size [for the patient]," explains Birchall.

Once the transplant has been grown from the patient's own stem cells, a surgeon will cut it to the right shape while fitting it to the patient's larynx. Because these lab-grown transplants are made from the patient's own cells, they don't run the same risk of immune system rejection that conventional donor organs do.

"This will be the first time these technologies have been trialled in a proper, controlled environment," says Birchall, who hopes that, if successful, the technique will be used for other types of organ transplants.



Your own replacement organs could soon be growing in the lab

CROPS TO SOAK UP FERTILISER FROM THE AIR

IN 2014, RESEARCHERS will begin genetically altering crops in an attempt to allow them to capture nitrogen directly from the air, instead of from fertilisers in the ground. Most plants get their nitrogen from the soil, usually from decayed organic matter or from synthetic fertilisers. It is thanks to these inorganic fertilisers that we are able to grow enough crops to feed the global population, but producing them is energy-intensive, uses fossil fuels, and releases greenhouse gases.

Now a project backed by Microsoft's Bill Gates is experimenting with special types of bacteria that can take nitrogen from the air and pass it onto some legumes, which include peas and beans. "Legumes can utilise bacteria in their roots, and the bacteria provide a biologically available form of nitrogen to the plant," explains Giles Oldroyd of the John Innes Centre, a plant scientist involved in the project. "If we can transfer these capabilities to cereals, then we can wean agriculture from its addiction to inorganic fertilisers."

In 2014 Oldroyd and his colleagues will insert genes into maize to enable them to partner with bacteria that can absorb nitrogen from the air.

SCIENTISTS TO BUILD A GENOME FROM SCRATCH

IN 2014, AN international team is set to finish building the first artificial yeast chromosomes. It's part of a global effort to build a genome from scratch that is capable of powering a yeast cell. The ambitious project began during the last decade in an effort to understand what genes are needed for a cell to survive.

Scientists traditionally 'knock-out' genes one by one and observe the effects, but the yeast team is adopting the opposite approach. Its building a genome up piece by piece, and seeing if it is able to sustain life. One question the project hopes to answer is how important gaps in genes are. 'Eukaryotic' cells that make up animals, plants and yeast all have regions of DNA in the middle of their genes that do not code for proteins. Bacterial genomes do not have these gaps. "[These gaps] are found in all eukaryotic genomes, but in yeast there are not that many and none are thought to be essential," says Imperial College London scientist Tom Ellis. "So let's get rid of them and see if the cell survives."



Injecting a plant with a virus is enough to make it produce proteins to develop vaccines

"Plant-grown vaccine compounds could be cheaper and faster to grow"



A researcher at Imperial College London is part of a team building artificial yeast chromosomes

PLANTS TO BE CULTIVATED TO GROW FLU VACCINES

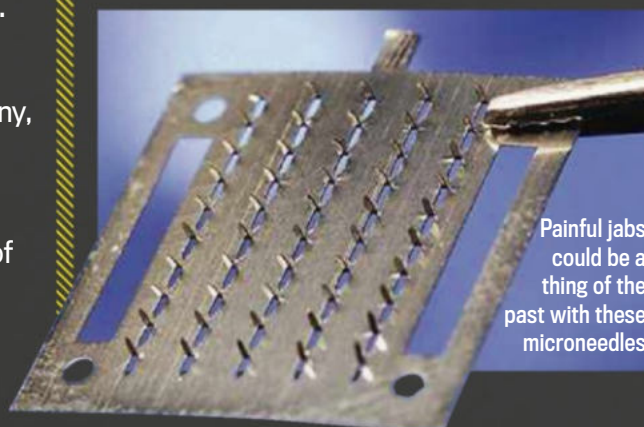
INSTEAD OF FERMENTING mammal cells or using chicken eggs to produce vaccine chemicals, we might soon be growing them inside plants instead. The predominant strains of seasonal flu vary from year to year, and it's a race against the clock to develop a new vaccine each year and to produce it in large enough quantities.

Plant-grown vaccine compounds could be cheaper, faster to grow, and less susceptible to contamination. George Lomonosoff and his team at the John Innes Centre, Norwich, have developed a method for producing vaccines in plants. They have already produced a vaccine for the Bluetongue virus that affects farm animals and in 2014 they will push forward with human illnesses like flu.

"Egg-based systems are only just fast enough to produce a vaccine in time," explains Lomonosoff. A Canadian company, Megicigo, is now using Lomonosoff's techniques to produce flu vaccines. It has already shown that these plant-based techniques can produce 10 million doses of flu vaccine within a month, and has begun trialling experimental vaccines in humans.

THE JAB TO BE REPLACED WITH PAINLESS INJECTIONS

TERRIFIED OF NEEDLES? If so there is good news coming in 2014. Researchers at Queen's University Belfast are developing a painless way to inject vaccines using tiny needles, around half a millimetre in length. These microneedles don't hurt when pressed into the skin, where they become soft and release their medicine. Throughout 2014, Ryan Donnelly and his colleagues will work on manufacturing them on an industrial scale. Because the needles become soft, Donnelly says they could stop diseases spreading through hospital accidents, "particularly in the developing world, where the unsafe use of hypodermic syringes is widespread."



Painful jabs could be a thing of the past with these microneedles

JANUARY 2014

INSECT RADAR

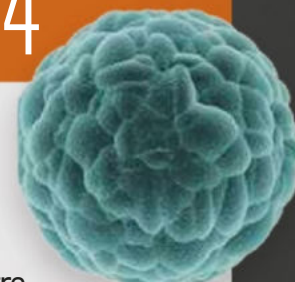
Scientists in the UK will begin building a radar network capable of detecting and monitoring the movement of pollinator insects on a massive scale.



JULY 2014

CANCER IN THE SPOTLIGHT

The UK will be home to the world's most advanced imaging centre dedicated to studying cancer at the Institute of Cancer Research. It will use the latest MRI and ultrasound technologies to investigate tumours.





TECHNOLOGY

'4D' PRINTED MATERIALS WILL BE ABLE TO ADAPT TO THE ENVIRONMENT

WE MIGHT BE some way off the dream of a 3D printer in every home, but the manufacturing industry is certainly diving in: the European Space Agency has printed metal parts that can withstand temperatures of 1,000°C, and General Electric is preparing to mass-print critical jet engine parts. It's fast progress, but why stop at 3D? A collaboration between MIT's Self-Assembly Lab and the 3D printing company Stratasys has produced an even more amazing process they've called '4D printing'.

Using a Stratasys Connex 3D printer, the team can create objects that are able to change shape after they're printed. By programming different material properties into the particles of the printed object, the team can use an external stimulus such as water or heat to activate a self-assembly process in which the object folds itself into a different shape.



Right now it's relatively low-level – a flat sheet folds itself into a cube, a printed tube folds itself into a 3D frame (pictured above). But the team is looking ahead to real-world applications: think water pipes that could expand or contract, or even undulate to move the water through them. "You design something, you print it, it evolves," says MIT's Skylar Tibbits. "It's like naturally embedding smartness into materials."

And it's not just MIT working on the technology: the US Army Research Office has given a trio of scientists an \$855,000 grant to develop their own 4D materials. Ralph Nuzzo of the University of Illinois predicts the creation of "a fabric that responds to light by changing its colour, to temperature by altering its permeability, and even to an external force by hardening its structure". We're not close to that stage yet, but there's no doubt 4D printing will have a big scientific role to play in 2014.



LASER WEAPONS TO ENTER SERVICE

IT STILL SOUNDS too sci-fi to be real, but lasers are indeed coming to a warship near you. The US Office of Naval Research (ONR) has announced it will deploy a solid-state laser for testing aboard the USS Ponce in 2014, two years ahead of schedule. It follows successful demonstrations of the technology destroying moving targets, including a small boat and remote aircraft.

The laser can deliver anything from a non-lethal disabling blow all the way up to full destruction, and it will complement rather than replace missiles. The power levels will be around 100kW – not enough to engage a cruise missile at a tactically

useful range, but capable of matching current ship-defence weapons. Lasers require no propellants or explosives so they're safer, and they run on electricity, making them cheaper than standard weapons. The ONR estimates the cost of a shot of directed energy will be under \$1, compared to hundreds of thousands for a missile.

"The future is here," says Peter A Morrison, programme officer for ONR's Solid-State Laser Technology Maturation Program. "The solid-state laser is a big step forward to revolutionising modern warfare with directed energy, just as gunpowder did in the era of knives and swords." We wouldn't want to be the ones bringing a gun to a laser fight.

“The laser is a big step forward to revolutionising warfare, just as gunpowder did in the era of swords”



A laser weapon system like this test version will soon be installed on the USS Ponce, which should be zapping things this year

EVERYTHING TO BECOME TOUCH-SENSITIVE

USING CAMERAS AND projectors, Fujitsu's new technology transforms any object into a touchscreen. Imagine hovering your finger over an open atlas and seeing a digital cursor move across the maps beneath, then tapping a country and seeing a video appear on the table.

Fujitsu's tech uses a desktop bracket that aims a camera down onto the objects on a table and produces a map of its surface-height co-ordinates. The image-processing software can then match your finger movements to those co-ordinates and change the projected table overlay accordingly. Fujitsu is busy testing its system with the goal of producing a commercial product in 2014.

CYBORG COCKROACHES RESCUE DISASTER VICTIMS

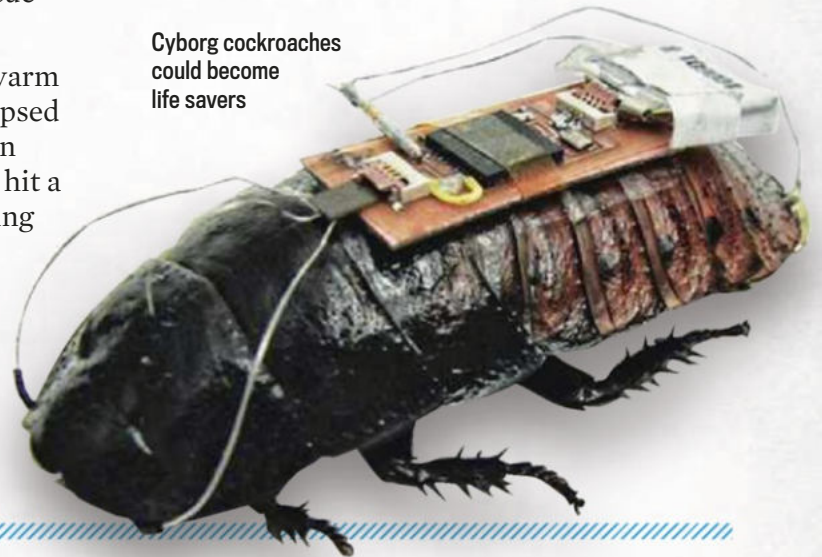
WE'VE SEEN MANY innovative ways to harness technology in disaster zones, but the latest is truly bizarre. You might have your doubts over the usefulness of a remote-controlled cockroach, but that didn't stop researchers at North Carolina State University from running with the idea. They used a system of blind wall following, and the search and rescue cockroach was born.

The idea is that you release a swarm of cyborg cockroaches into a collapsed building and let them spread out in random directions. Any time they hit a wall, they're directed along it, giving operators sensor feedback on the space they're exploring. Repeat the process a few more times and you build up a map of edges revealing an area that would otherwise be out of the rescuers' reach.

The team now plans to experiment with adding radiation and chemical sensors to the practically indestructible little creatures.

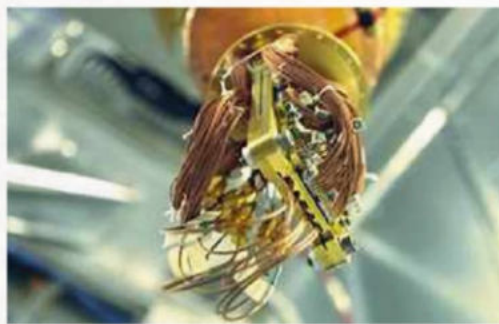
Believe it or not, this all started as a Kickstarter appeal to fund the DIY 'RoboRoach' control kit. The kits are still available, along with a box of live roaches.

Cyborg cockroaches could become life savers



GOOGLE AND NASA FIRE UP A QUANTUM COMPUTER

GOOGLE AND NASA have teamed up to build a cutting-edge artificial intelligence lab. They believe the power of quantum computing is the key to solving the most challenging computer science problems. They'll use their new D-Wave Two – the



The heart of the D-Wave quantum computer

world's most advanced quantum computer – to help them build better models of the world and make more accurate predictions, from diseases and the environment to simply making a better search engine. Google is also said to be using the computer to improve the blink-detection algorithm used in the eagerly awaited smart eyewear, Google Glass. D-Wave founder Geordie Rose says it's the first time a quantum algorithm has been used to develop commercial software.

NOVEMBER 2014

SUPER-HIGH SKYSCRAPER

The 838m Sky City in China is due to take the crown of world's tallest building. Amazingly, building work hasn't even begun: its prefabricated modules are projected to go up in an incredible seven months.



DECEMBER 2014



SPACE TOURISTS ARE GO

Customers paying \$250,000 each are expected to take their seats on Virgin Galactic's SpaceShipTwo for the trip of a lifetime into suborbital space, including six minutes of weightlessness.

PHYSICS

PLANCK TO UNRAVEL MYSTERIES OF THE EARLY UNIVERSE

THE PLANCK SATELLITE is now dead and drifting in space, but its data lives on. In mid-2014, ESA will release the next batch. It should tell us more about the way the large-scale structure of the Universe was born.

Planck completed its mission to map the radiation from the Big Bang, known as the cosmic microwave background (CMB) radiation, in late 2013. It shows the remnants of the light that first flowed through the Universe when it was just 370,000 years old. Now cosmologists are working on extracting a subtler signal, known as polarisation. Expected this year, the data will tell us more about the temperature fluctuations and the way these grew into huge clusters of galaxies. And a year later, cosmologists anticipate isolating the B-mode polarisation. This could provide a crucial test of 'inflation',

which describes how the Universe underwent a period of rapid expansion a fraction of a second after the Big Bang.

A closer look at the data might also help explain the incompatibility between gravity and the other three fundamental forces. Gravity has not been successfully explained at a quantum level, but Planck could change this, bringing our understanding closer to a unified 'theory of everything'. Sabine Hossenfelder at Stockholm's Nordic Institute for Theoretical Physics says: "Quantum gravitational effects are normally very weak, but were strong in the early Universe. The CMB spectrum can carry imprints from the early phase of the Universe in its polarisation pattern. Planck should be able to tell the good from the bad models and show how our Universe started its life."



The Planck telescope finished its mission in 2013, but the scientific bonanza to be had from its data is only just beginning

JAPAN WILL LAUNCH A QUANTUM NETWORK

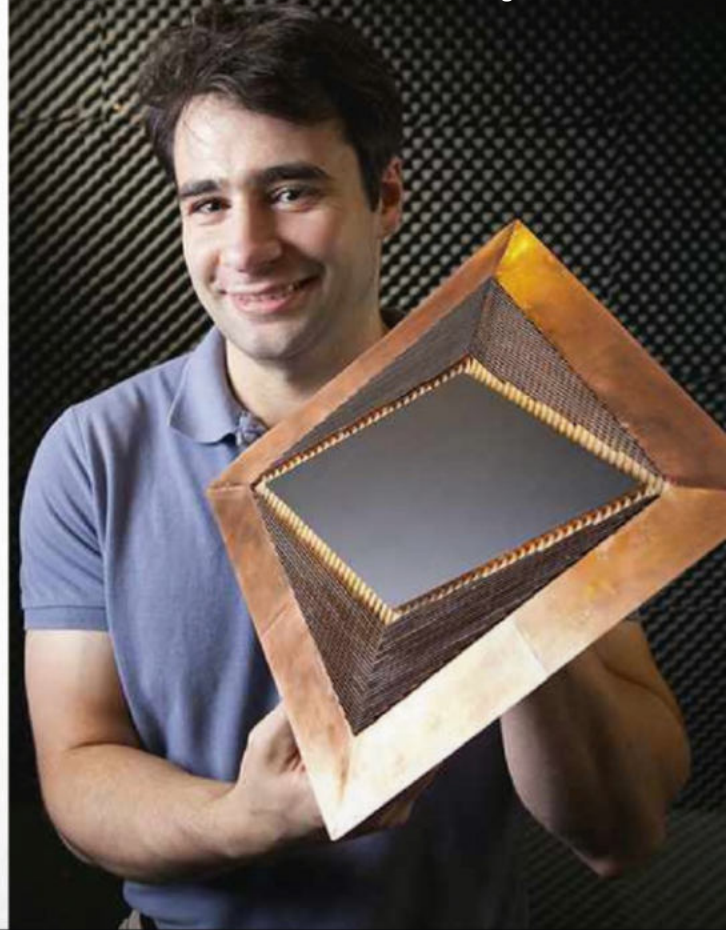
QUANTUM PHYSICS IS strange. It suggests that two particles, even on opposite sides of the Universe, can become entangled, with a change in one instantly reflected in another. An obvious application of 'quantum entanglement' might be instant communication, but it is looking more promising in encryption, where it can generate an unbreakable key that cannot be intercepted without the interception being detected. The first step towards this comes in 2014 with the launch of SOCRATES (Space Optical Communications Research Advanced Technology Satellite) by the Japanese Space Agency. This will distribute entangled pairs of particles to act as quantum keys, the precursor of a worldwide entanglement network.

HOW WE'LL SILENCE ANYTHING

THERE ARE TWO ways to achieve cloaking. One is to cover one side of an object with cameras and the other with a screen, showing an image of what is behind. This only works when seen from a single direction. However, metamaterials, specially structured substances that bend light around an object, render it truly invisible. The latest experiment in 2013 hid a 7.5cm-radius cylinder from microwaves. In 2014 this should be further enhanced, and will be extended into auditory cloaking. This would deaden any sound from a source to the rest of the world. Professor Steven Cummer of Duke University in the USA commented: "The field of acoustic metamaterials, which can be used to manipulate sound waves is advancing rapidly... I think we will see some interesting applications in 2014."

"Auditory cloaking would deaden any sound from a source to the rest of the world"

Metamaterials specialist Nathan Landy of Duke University poses with a metamaterials-based cloaking device



FUSION COULD BECOME SELF-SUSTAINING

NUCLEAR FUSION, THE power source of the Sun, is an energy producers' dream - no carbon emissions, low-level waste and a near-inexhaustible fuel. But making fusion reactors viable is immensely difficult. The US has long supported an approach that blasts a target with powerful lasers. The light vaporises the material with such intensity that it heats and compresses its interior, initiating fusion.

The world's leading experiment at this is the National Ignition Facility (NIF) in California. Here, 192 beams focus onto a tiny target. In 2013, NIF achieved a small milestone in creating a reaction where more energy was given out than zapped at the target. But much more energy was put into the system than hit the target, so this is far off the Holy Grail of 'break-even' where a reactor produces useful energy. Break-even won't occur in 2014, but the hope is for nuclear fusion to take over from the lasers with alpha heating. The energy from fusion then keeps the reaction going. Some alpha heating was observed in 2013, but if 2014 can make this more substantial, fusion energy will be another step towards being fully self-sustaining.

The heart of the National Ignition Facility where a small pellet of material is blasted with lasers to initiate a fusion reaction

SEARCH FOR ANTIGRAVITY TO STRETCH THE LAWS OF PHYSICS

WITH THE LARGE Hadron Collider resting in 2014, CERN's Alpha-2, the second phase of a project studying antimatter, will get a chance in the limelight. To create antimatter, constituents of atoms called protons are accelerated to high speeds in CERN's proton synchrotron, then smashed into a block of metal. The energy of the collision produces proton/antiproton pairs. The antiprotons are antimatter particles. Travelling at near light speed, they're funnelled off magnetically to the antiproton decelerator, which slows them by passing them through a cloud of electrons. They are then combined with positrons to make atoms of antihydrogen - the antimatter equivalent of hydrogen.

Alpha-2 will use a laser to measure antihydrogen's spectrum, comparing it

with conventional hydrogen, to hunt for differences in its response to the laws of physics. The scientists will also try to assess how antihydrogen responds to gravity. Antimatter may have negative gravitational mass, repelled by the gravitational field of the Earth. In the experiment, detectors will check whether antiatoms drift up or down. Should Alpha-2 discover that antimatter has negative gravitational mass it will mean re-writing the laws of physics. Scientists would have to revisit General Relativity - a fundamental law of physics that states that acceleration and gravity are indistinguishable - since antimatter would act differently under gravity and acceleration.

It might seem like a long shot, but CERN physicist Jeffrey Hangst was looking ahead with some optimism: "We are very excited about the future and are working hard to get the Alpha-2 experiment up and running." ■



ESA's Aeolus satellite undergoes testing - it's set for launch in 2013

The Alpha-2 experiment is installed, ready to begin probing the mysteries of antimatter

ADVERTISEMENT FEATURE



Pictures above taken using the
Canon PowerShot G16



**Canon PowerShot G16
specifications**

- > 12.1-megapixel CMOS sensor
- > DIGIC 6 image processor
- > f/1.8-2.8 28mm lens with 5x optical zoom
- > ISO up to 12,800
- > High-speed autofocus
- > 1080p video
- > Wi-Fi enabled
- > Weight: 356g





Never miss a shot

Time, tide and those all-important action photos wait for no-one – which is why the Canon PowerShot G16 has been built with speed in mind. Fast and supremely responsive, this is a camera that offers superfast shooting to capture those precious moments.

When it comes to 'blink and you'll miss it' photo opportunities, you're in safe hands with the Canon PowerShot G16. The camera powers up as soon as you hit the on button, and boasts super-fast autofocus, taking less than a quarter of a second to bring your picture into crystal-sharp focus. And there's no lag involved when you fully depress the shutter button to take the picture.

Action photos are no problem with the PowerShot G16, its continuous shooting mode lets you capture a burst of five images at 12.2

frames per second (fps). Then, because there's no buffer involved when shooting 9.3 fps, it'll keep going until your memory card is full. So whatever fast-moving subject you're trying to capture – whether it's a kingfisher landing on a branch, that crucial winning goal or perfecting a 360 skateboard flip you'll come away with the results you want.

The PowerShot G16 doesn't just let you take pictures quickly, it also makes it easy to share them instantly with friends and family, thanks to built-in Wi-Fi and access to Canon's own cloud service, CANON iMAGE GATEWAY. As soon as you've taken your pictures, you can transfer them to your computer or smartphone or upload them to social media services such as Flickr, Facebook and Twitter at the touch of a button – without needing to mess around with cables or card readers.

Not only does the PowerShot G16 take super-fast, super-crisp action photos at the drop of a hat, it also takes stunning macro images and shoots MP4 videos (including in slow-motion) at a range of resolutions. Plus it comes with a host of different shooting modes to make getting the perfect shot every time a breeze – in low light and in dazzling sunshine! The PowerShot G16 also offers a full range of features you'd expect to find on a DSLR including aperture and shutter speed controls, ISO adjustment up to 12,800, exposure compensation, automatic bracketing, optical viewfinder and a hotshoe for an additional flash unit. No wonder Canon is calling this "the compact for experts".

Canon  **CanonUKLtd**

FLYING SOLO

From Leonardo da Vinci's flying machines to the jet pack at the LA Olympics, we've dreamed of flying like a bird. Now there's a new breed of solo flying machines ready to take off

WORDS: SEDEER EL-SHOWK



For video of flying machines in action, see our iPad app





JETMAN WING

F

OR DAREDEVILS looking for the thrill of speed and the freedom of unencumbered flight, nothing can beat a personal jetpack. Powered by four miniature jet engines, this wing unit developed by Swiss pilot and aviation enthusiast Yves

Rossy fits the bill. It can hit speeds of up to 300km/h (186mph) and is manoeuvrable enough to pull off loops and rolls.

Launched from a helicopter, the wings are guided entirely by the pilot's body movements – there are no rudders, ailerons,

or flaps. A throttle attached to the right hand controls thrust; the only other instruments are an altimeter to report altitude and a timer to keep track of fuel. There's enough fuel to fly for around 10 minutes, after which Rossy is able to land safely using a parachute.

Protected from the engine exhaust by a heat-resistant suit, Rossy manoeuvres the carbon-fibre wings by tilting his head and angling his shoulders. It takes a lot of concentration to avoid an uncontrolled spin, "I stay relaxed, avoiding any fast movements, like a ski-jumper," says Rossy. In the event of a spin, the wing unit can

be separated from the pilot, allowing both to independently parachute to safety.

Rossy unveiled his invention to the world in a flight over the Swiss Alps in May 2008. Four months later, he made history by using the jet-powered wings to cross the English Channel 99 years after Louis Blériot's famous flight. Last November he could be seen flying around Mount Fuji, circling the volcano nine times over the course of a week.

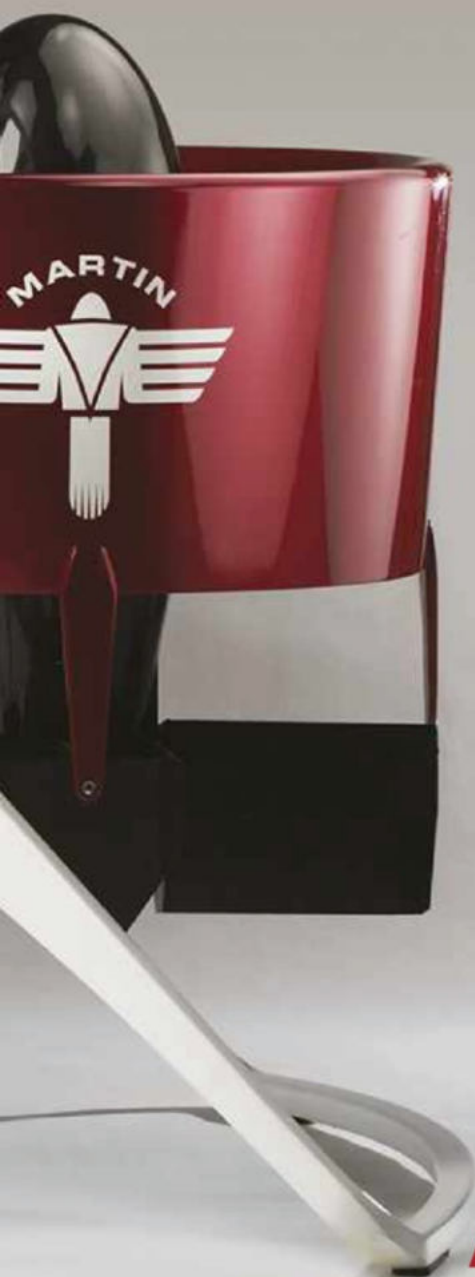
Don't expect to see this wing unit in stores anytime soon. Difficult to use and expensive to develop, it's likely to remain one of a kind for the moment.





The Martin Jetpack can hit a top speed of 74km/h (45mph) and operates at a recommended cruise height of 500ft (150m)

A test pilot takes to the skies with a Martin Jetpack



MARTIN JETPACK



THOUGH ITS MAKERS claim to have built 'the world's first practical jetpack', the Martin Jetpack is actually powered by a pair of ducted fans, not a jet engine. Constructed from advanced lightweight composites, it's the culmination of over 30 years of research by founder Glenn Martin, who started the project in his garage on a budget of just NZ \$20 (£10) per month.

The Martin Jetpack has been designed with an emphasis on safety and ease of use. It can cruise at 56km/h (35mph) for up to 30km, and includes a specially

designed parachute that is fired from a casing in case of failure. Protected by a Kevlar roll cage, the pilot controls pitch and roll with one hand and throttle and yaw with the other. "We are finding that even without flying experience, individuals are able to learn to fly the Jetpack in under five hours," said Peter Coker, CEO of Martin Aircraft.

The company is already accepting orders, with a target launch date of mid-2014 for police and other government agencies. Sales to private individuals are expected to start in 2015, though the US \$100,000 price tag means that it will remain the preserve of the lucky few for a while yet.





We're not sure if this would qualify for use in a cycle lane...



The flying bike remains remote controlled for now - but human test flights are planned

FLYING BIKE



THE SCENE IN the film *E.T.* when Elliott takes flight on his bike, iconically silhouetted in front of a full Moon, could become a reality. That is if a crack team of engineers have their way. Their flying bicycle uses six

electrically powered propellers: two large pairs over the wheels providing lift, and smaller ones on either side for manoeuvring and balance. Inspired by science fiction novels, the Czech companies Duratec, Technodat and Evektor, assisted by French company Dassault, launched the project in 2011. The first prototype was unveiled last June.

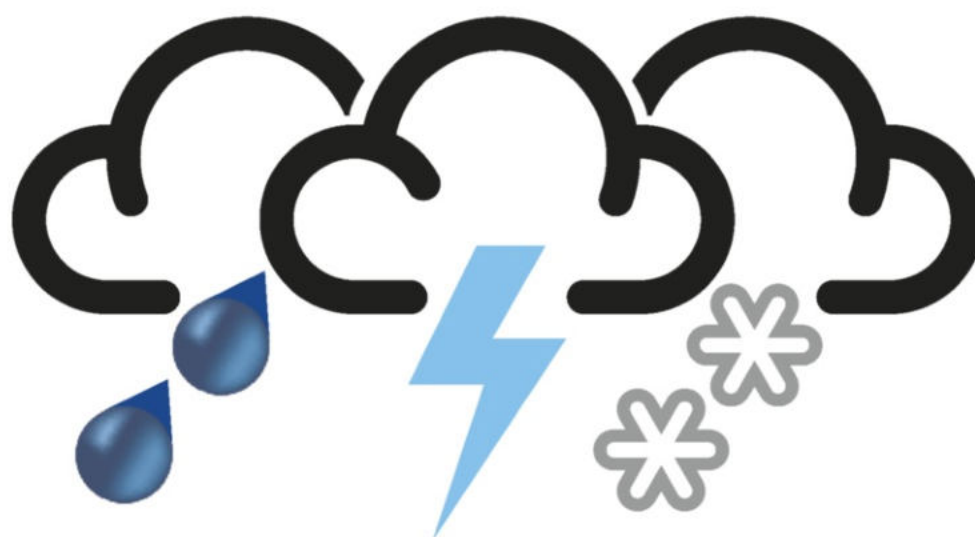
Although the bicycle carried a dummy during its remotely controlled demo flight, the team is hoping to test it with

a human rider in 2014 and is working to add a control unit. Unfortunately, it only flies for five minutes before the battery runs dry.

This limited prototype is just the first step towards the team's lofty goal. Their aim is to build a unit that works like a normal bike but can also take off for short, low-altitude flights, hopping over traffic or other obstacles. "We are still considering major changes," said Technodat engineer Jindřich Vítů, who stressed that the bike is "a proof of concept".

According to Vítů, a version that can be flown by a human will be ready in a year. If you're impatient to fly something before then, check out the Flyke from Germany company Fresh Breeze, a recumbent tricycle equipped with a paragliding wing and a motor drive. ■

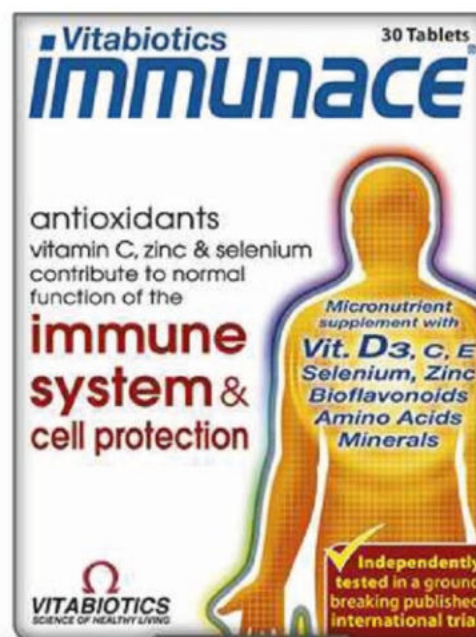




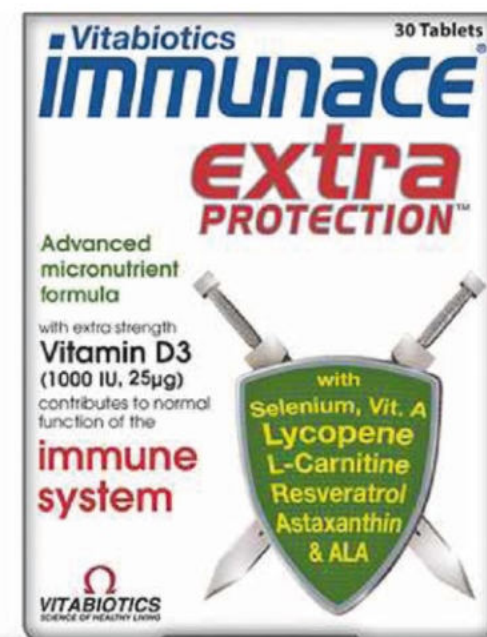
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Immunace® has been developed by Vitabiotics' pharmacists and leading scientists in nutritional research to help maintain all round health and vitality, whilst providing specific nutrients such as vitamin C, zinc and selenium which contribute to the **normal function of the immune system.**

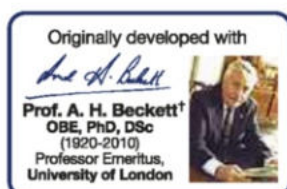
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Immunace® Original



Immunace® Extra Protection




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**with 1000 IU
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Supplements may benefit those with nutritionally inadequate diets. † Professor Beckett is not cited in the capacity of a health professional, but as a product inventor and former Chairman of Vitabiotics. *(IRI value data. 52 w/e 13 Jul, 13).

Q&A

YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL



SUSAN BLACKMORE

Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*



DR ALASTAIR GUNN

Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester



ROBERT MATTHEWS

After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University



GARETH MITCHELL

Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service



LUIS VILLAZON

Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com

or post to *BBC Focus Q&A*, Tower House, Fairfax Street, Bristol, BS1 3BN

MELANIE GARDER, LONDON

How long can a structure last in a desert before being swamped by sand?



The home of Anakin Skywalker is slowly being consumed by the desert

A BUILDINGS DON'T ACTUALLY sink into the sand, they are covered as it's blown sideways by the wind. Without any plants to hold the sand in place, it is blown into horseshoe-shaped dunes, called barchans. Each grain gets blown from the bottom of the dune up to the crest and then tumbles down the steeper slope on the leeward side. This means that the barchan as a whole gradually creeps downwind at about 15m per year. In Tunisia, the set of Anakin Skywalker's home, used for *Star Wars Episode 1*, is currently being engulfed. In another five or six years it will be completely covered. **LV**

PHOTO: ALAMY

In Numbers

348

miles per gallon is the fuel economy that the world's first road-ready car built using 3D printing, the Urbee 2, will hopefully achieve.

Q ALAN HUGHES-HALLETT, WANSTROW

What is the maximum number of names a person can remember?

A THERE'S NO KNOWN limit! If you ask a mnemonist or memory savant to learn a list of names they may remember thousands, tens of thousands or even hundreds of thousands with no trouble, just as they can learn lists of thousands of digits. Some people, who have a neurological condition called 'hyperthymesia', remember everything that happens to them every day, including the name of every person they have ever met.

The rest of us evolved to cope with no more than about 150 social relationships. This is known as Dunbar's number after the anthropologist Robin Dunbar. He discovered that groups of hunter-gatherers, units in armies, divisions in businesses and many other groups tend towards a limit of 150. And it seems that social media do not change our basic nature. Even people who have thousands of 'friends' on Facebook rarely maintain more than 150 meaningful relationships. **SB**



Some people don't need name tags and can put a name to thousands

Q LEIGH MCMAHON, BY EMAIL

Are Saturn and Jupiter's moons tidally locked?

Janus; 179km across

Pandora; 81km across

Enceladus; 504km across

Rhea; 1,528km across

Mimas; 396km across

A quintet of tidally locked Moons orbit Saturn; the planet has 62 moons with confirmed orbits

A A MOON IS 'tidally locked' if it rotates about its axis in about the same time as it orbits its parent body. The Moon is tidally locked to Earth, which is why we see essentially the same face presented to us at all times. Tidal locking is a gravitational effect and whether it happens or not depends on the sizes and proximity of the two objects. Under the right conditions, the parent body's gravity causes the moon to elongate slightly. Forces acting

differently on the nearer and further side of the moon's bulge then create a 'torque' that eventually alters the moon's rotation speed to match its orbit.

Saturn and Jupiter both have tidally locked moons. For Saturn, 15 of its 62 moons are tidally locked, including Titan, Enceladus and Calypso. For Jupiter, eight of its 67 moons are tidally locked, including the four largest 'Galilean' moons: Ganymede, Callisto, Io and Europa. **AG**

Q RICHARD O'NEILL, GLASGOW

Why do goats have such good balance?

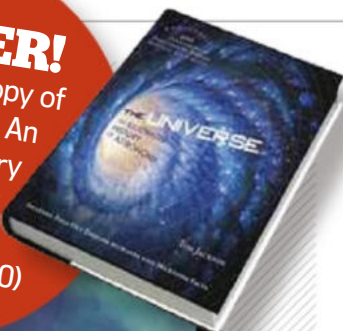
A GOATS ARE ADAPTED to living and feeding on steep, rugged slopes. Their slim bodies help them creep along next to near-vertical walls and their cloven hooves have two toes which can spread out wide, improving their balance and allowing them to grip onto rocks or even the branches of trees. The soles of their feet are soft and the rough pads under each toe provide extra grip. They also have two vestigial toes higher up their legs, called dewclaws. These are found on other species, including cats and dogs, but goats' dewclaws are much stronger and stubbier and help them clamber up branches, or scramble down sheer cliff faces. **SB**

The ultimate rock climber: the humble goat



QUESTION OF THE MONTH

WINNER!
Divya wins a copy of
*The Universe - An
Illustrated History
Of Astronomy* by
Tom Jackson
(Worth Press, £20)



The appendix (pictured on the left in this X-ray image) could be a safe-haven for friendly bacteria in emergency situations

Q DIVYA BENNY, WESTON SUPER MARE

What is the function of the human appendix?

A THE APPENDIX WAS classically regarded as unnecessary – even its name implies that it is a leftover bit. It's a thin tube, about the size of half a pencil, that sticks out of the cecum, which is a pouch at the start of the large intestine. Charles Darwin thought that our ancestors ate a lot more plant roughage than us and needed a larger cecum to digest it, so the appendix was originally a useful compartment of the intestine that had dwindled through millions of years of disuse. Koalas, which eat very indigestible leaves have a two-metre-long cecum that is essentially a giant appendix.

Certainly it's true that you can amputate the appendix without any obvious long-term consequences for the patient. But that same

argument applies to a toe. Being able to get along without something doesn't mean it's entirely useless. Recent research that compared the intestines of 361 mammals found that 50 different, quite unrelated, species have an appendix. This means that the appendix must have evolved independently at least 32 times, which suggests it must be doing something useful.

It's now thought that the appendix acts as an emergency bunker for your gut bacteria to shelter in. Its narrow opening and out-of-the-way position mean that bacterial infections don't normally get inside it. So after diarrhoea has flushed the last of any bad bacteria out of your intestines, the good guys can emerge from the appendix and re-colonise your colon. **LV**

Q TOM WILLIAMS, HEREFORD

Where can you find the fastest broadband speed in the world?



Hong Kong: a city in the internet fast lane

A AND THE WINNER is... Hong Kong! Internet users there enjoy top speeds of 63 megabits per second, according to the most recent figures from the internet firm Akamai. Hong Kong's blistering broadband speeds compare to a worldwide average of 18.4Mbps. The UK is number 12 on the list with average speeds of 36Mbps. **GM**

Q STEVEN DAVE, REDRUTH

Does your body's level of hydration affect your blood's viscosity?



Keep your blood running smoothly by staying hydrated

A BLOOD VISCOSITY, OR how thick your blood is, is partly determined by the number and size of your red blood cells. These make up 41-53 per cent of the blood volume in men and 36-46 per cent in women. This value is higher if you are obese, which can increase blood viscosity by as much as 15 per cent and can cause a heart attack. But being dehydrated can also have an impact. One study found that just sitting in a warm room for four hours without drinking was enough to increase blood viscosity by 10 per cent. **LV**

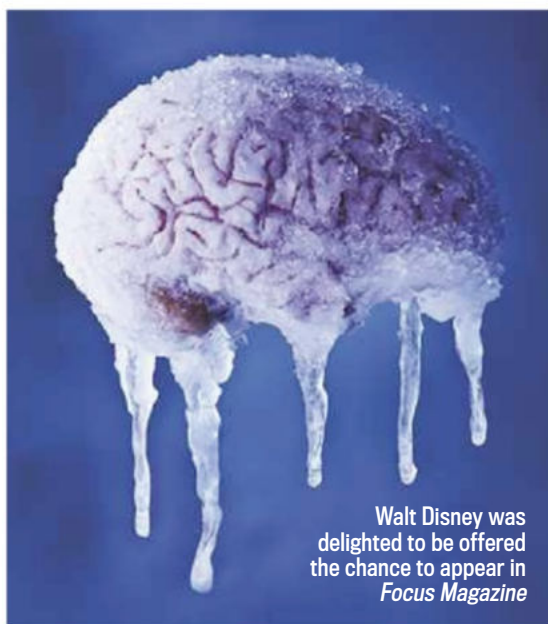
? Did you know?

The air around a lightning strike is the hottest place on Earth. For a split second temperatures hit 30,000°C; hotter than the surface of the Sun.



Q MARTIN BALSON, FIFE

Why do cold drinks give me 'brain freeze' and how do I avoid it?



Walt Disney was delighted to be offered the chance to appear in *Focus Magazine*

A ANYTHING COLD AGAINST the roof of your mouth cools the brain, which is right above it. To maintain temperature, the anterior cerebral artery dilates to bring more warm blood to the brain. If the cooling is very sudden, the artery dilates too quickly and the pressure in the brain jumps up, which gives you a headache. Drinking more slowly, with pauses to warm your mouth back up, is normally all you need to do to avoid it, but brain freeze is worse in people who are prone to migraines. **LV**

Q JENNY CRAMLEY, BASINGSTOKE

What gives substances their scent?

A SUBSTANCES GENERATE A smell when their molecules land on so-called olfactory neurones in our noses (which, for some things, is a pretty unpleasant thought). But the exact nature of the interaction is somewhat controversial. Until recently, it was believed it took the form of molecules physically docking with protein receptor molecules in the walls of the olfactory neurones, like keys fitting into locks. This in turn implied that molecular shape is what determines a specific smell. But this fails to explain

why some molecules with similar shapes can smell completely different, while others with quite different shapes can have a similar scent.

These conundrums have led Dr Luca Turin of the Alexander Fleming Research Centre, Athens, to suggest that molecular vibrations are critical. He's recently published intriguing evidence that molecular shape is not everything by showing that two molecules with identical shape but different vibrational properties can have a different smell. **RM**

Next time you smell something interesting, think about the substance's molecules jiggling around inside your nose



TOP TEN

BIGGEST MOONS IN OUR SOLAR SYSTEM



10. Oberon
Radius: 761km
Location: Uranus



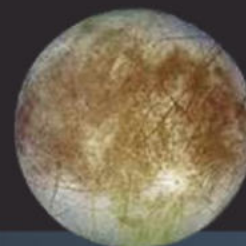
9. Rhea
Radius: 764km
Location: Saturn



8. Titania
Radius: 788km
Location: Uranus



7. Triton
Radius: 1,353km
Location: Neptune



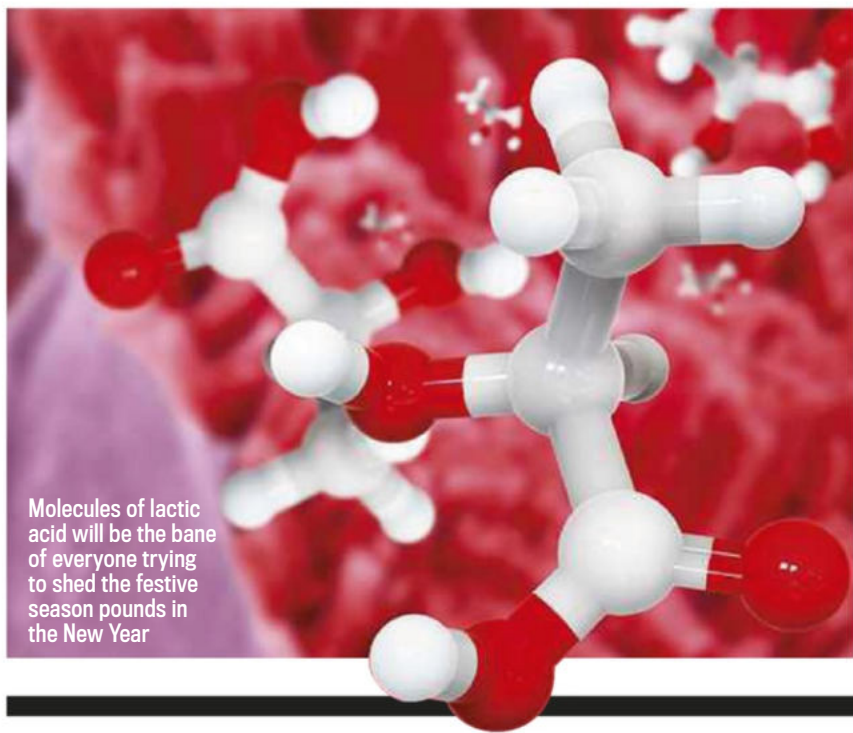
6. Europa
Radius: 1,561km
Location: Jupiter



5. Moon
Radius: 1,737km
Location: Earth

Q RICHARD DAVIS, POOLE

Why does lactic acid build up in our muscles?



A DURING AEROBIC exercise our muscles 'burn' glucose with oxygen to produce carbon dioxide, water and energy. But when we are exercising hard, the lungs can't keep up with the muscles' demand for oxygen. Rather than just giving up, our muscles switch to an *anaerobic chemical* reaction that doesn't need oxygen.

This is less efficient because it doesn't produce as much energy per molecule of glucose burned, but it's better than nothing. Unfortunately, instead of water and carbon

dioxide, anaerobic respiration produces lactic acid as one of its waste products. If you exercise hard, this will be produced faster than your bloodstream can transport it away to your liver where it is processed and broken down.

As the level of acid builds up in your muscles, you feel a burning sensation that acts as a warning that your muscles are almost out of energy. Like other sorts of pain, the 'purpose' is to signal that your body needs to rest. So, next time you go for a run bear your overworked body a thought and maybe catch your breath. **LV**

Q ROY MUSSELBROOK, RAMSGATE

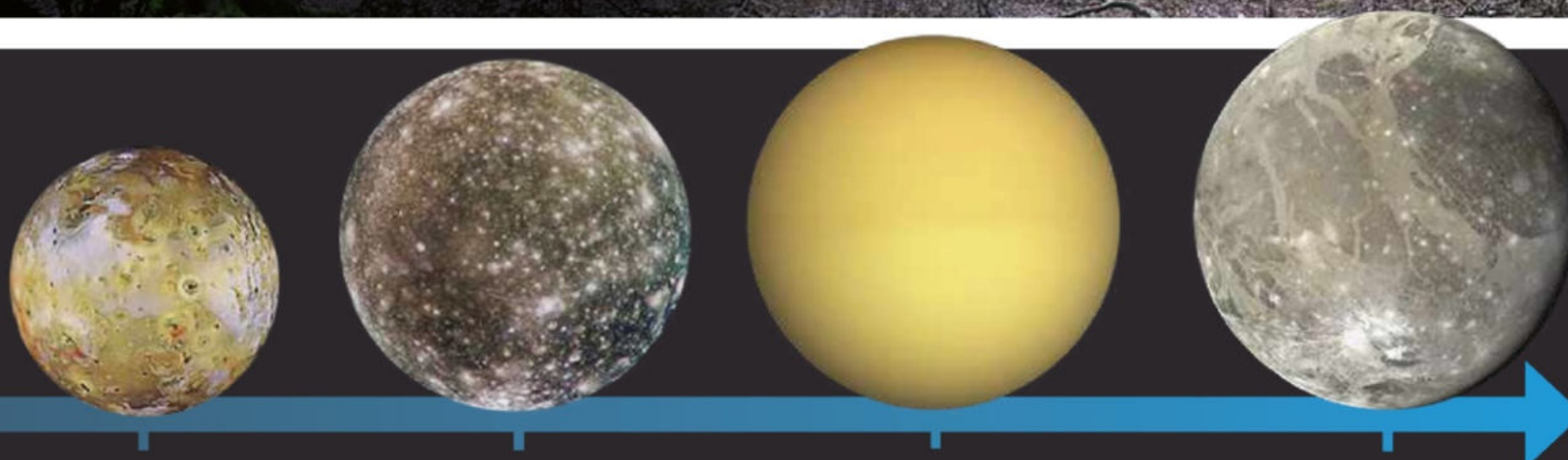
Are some plants better than others at sucking up carbon dioxide?

A PLANTS USE CARBON dioxide (CO_2) during photosynthesis to make glucose. It takes six molecules of CO_2 to make every molecule of glucose, and this basic building block is then used for energy and to make the structure of the plant itself. This biochemical reaction is the same for all plants, but the faster a plant grows, the more carbon dioxide it will use up per second. By that measure, bamboo might be the best at sucking up CO_2 . However, fast-growing plants tend

not to live long and when a plant dies, all the carbon in the plant is broken down by insects, fungi and microbes and released as CO_2 again.

So the plants that are considered the most adept at locking away carbon dioxide from the atmosphere are the longest-living ones, with the most mass – hardwood trees. It's all temporary though. Eventually every plant returns all the carbon dioxide it uses back to the atmosphere. **LV**

Hardwood trees will happily feast on your exhaust fumes, but you probably don't need to go to these lengths



4. Io

Radius: 1,821km
Location: Jupiter

3. Callisto

Radius: 2,410km
Location: Jupiter

2. Titan

Radius: 2,576km
Location: Saturn

1. Ganymede

Radius: 2,631km
Location: Jupiter



Astronaut Mark C Lee tests NASA's SAFER back pack high above Earth

Q ROGER BEEVER, HUDDERSFIELD

Could an astronaut be rescued if he/she became untethered on a space walk?

A NASA HAS DEVELOPED a sort of jetpack called SAFER (Simplified Aid For EVA Rescue), which fires compressed nitrogen from 24 thrusters to steer the astronaut back to safety if they become detached. Theoretically, astronauts could also vent some gas from their suits or even throw a tool in the opposite direction to push themselves forward. But the problem is that unless the thrust is exactly in line with the astronaut's centre of mass, they will start spinning uncontrollably and very quickly become disorientated. SAFER automatically detects rotation and uses its jets to keep the astronaut oriented the same way. **LV**

In Numbers

13.1 billion

years is the time it took for light to reach us from the most distant galaxy known. The light was emitted only 700 million years after the Big Bang.

Q CAROL FINLAY, CARDIFF

What makes Google so much more successful than other search engines?



What's the secret to Google's success?
Just google it!

A BEFORE GOOGLE, SEARCH results were less to do with relevance than who was paying for prominent listings. Early tools also matched search terms to sites based on a textual analysis of their pages. Websites often manipulated that by littering pages with irrelevant words inserted for the benefit of the search bots.

The breakthrough for Google was Larry Page's eponymous PageRank algorithm. It listed pages according to the number of sites linking to them. It

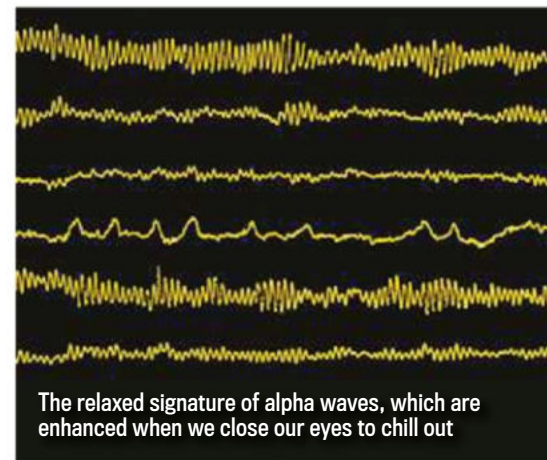
also weighted the results so that a few big pages linking to a site had more prominence than many small ones. Google's commercial advance was fuelled by AdWords, where advertisers pay for their websites to appear above the search results for the relevant keywords. The profits from advertising drove a huge research and development operation at Google, feeding back into an ever further refined engine, ever more targeted ads and more and more services. **GM**

Q DAVID DALTON, POOLE

Does a brainwave equate to a mental state?

A NO. THE TERM 'brainwave' comes from the patterns detected by an apparatus called the 'electroencephalogram' (EEG) that measures electrical signals from electrodes on the scalp. The overall frequency gives an indication of a person's mental state. For example, 'alpha waves' (8-13 per second) are associated with a relaxed state. But these surface waves are created from millions of small electrical signals in the underlying brain, so they are a very crude measure that could not equate to a precise mental state.

If you mean to ask whether any kind of brain process equates to a mental state then you are in the realms of seriously difficult philosophical questions. 'Identity theorists' say yes – mental states really are brain states. 'Functionalists' argue



The relaxed signature of alpha waves, which are enhanced when we close our eyes to chill out

that the function being carried out equates to mental states. For instance, if a human brain and a computer were both trying to solve the same chess problem they would be in the same mental state. **SB**



Q Where could the next natural disaster strike?

From methane belches to a deadly volcano, **Bill McGuire** reveals how nature is on the warpath

A EAST SIBERIAN ARCTIC SHELF METHANE OUTBURST



Ice and bubbles of gas mark the East Siberian Arctic Shelf as clouds of methane reach the surface

BELOW THE EAST Siberian Arctic Shelf, locked away beneath frozen submarine permafrost, is an estimated trillion tonnes of methane; one of the most potent of all greenhouse gases. Recent research reveals, however, that the permafrost seal is starting to crack so that methane, produced from the decay of organic material, is now bubbling up to the surface at a rate of 10 million tonnes a year. Scientists are now warning that, within a decade, a giant 'belch' could release a staggering 50 billion tonnes of methane in one go.

At a stroke, this would increase the amount of methane in the atmosphere 12 times over and raise global temperatures by 1.3°C, bringing forward dangerous climate change by 35 years. One estimate suggests that the impact on agriculture, weather and sea level rise could cost the global economy a staggering \$60 trillion.

A NORTH KOREA MT PAKTU ERUPTION



The lake-filled crater of Mount Paektu, a volcano that is due a deadly eruption

IN MOST PEOPLE'S minds, North Korea isn't associated with volcanic blasts, but Mount Paektu – Korea's tallest mountain – is known to have hosted one of the greatest eruptions of the last 10,000 years. Around 940AD, this monster volcano tore itself apart in a colossal detonation that left behind a 5km (3-mile) crater (now a lake) and dumped ash as far as southern Japan. Worryingly, for the local inhabitants and the 30,000 tourists that visit the volcano every year, recent swarms of earthquakes, swelling of the ground surface and gas emissions, suggest that it might be getting ready to go bang once again.

The fact that the volcano erupts every 100 years or so, and last exploded in 1903, has served to concentrate minds even further. UK volcanologists are now collaborating with the North Koreans to learn more about the internal workings of this particularly dangerous volcano.

A EQUATORIAL PACIFIC EL NIÑO



A dried up creek in the Philippines reveals the devastating effects of El Niño

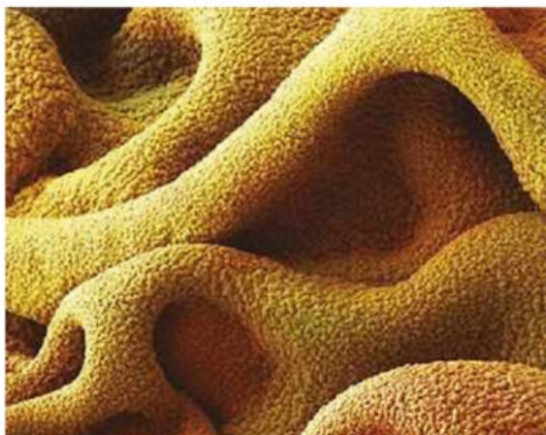
EL NIÑO IS the name given to the periodic accumulation of unusually warm water in the eastern Equatorial Pacific. The effects of an El Niño are widespread; the change in ocean conditions stirs up weather patterns across the planet, and usually not for the better. The particularly severe 1982-83 El Niño was blamed for at least 2,000 deaths worldwide and damage totalling \$13 billion.

Three years after the most recent El Niño faded, there are signs that another could start to build in spring 2014. Farmers and firefighters in Australia are on alert for the onset of the tinder box conditions that an El Niño brings, while places as far apart as California, Peru and eastern Europe brace themselves for torrential rains and floods.

BILL MCGUIRE is Emeritus Professor of Geophysical & Climate Hazards at University College London and author of *Waking The Giant*

Q LUIGI FILLETTI, MALTA

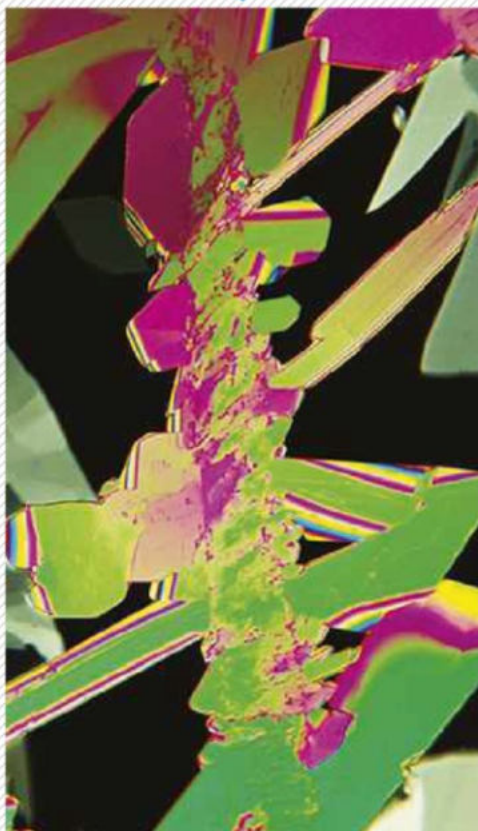
What makes glue a sticky substance?



A magnified image of superglue – doctors now use non-toxic variants instead of stitches

A GLUES ARE MADE from molecules whose electrons form bonds with those on the surface of other materials. Precisely what type of bond – and how strong it is – varies enormously, but many glues exploit so-called covalent bonding, where electrons are shared between the glue and the surface, making them hard to separate. **RM**

WHAT IS THIS?



KNOW THE ANSWER?

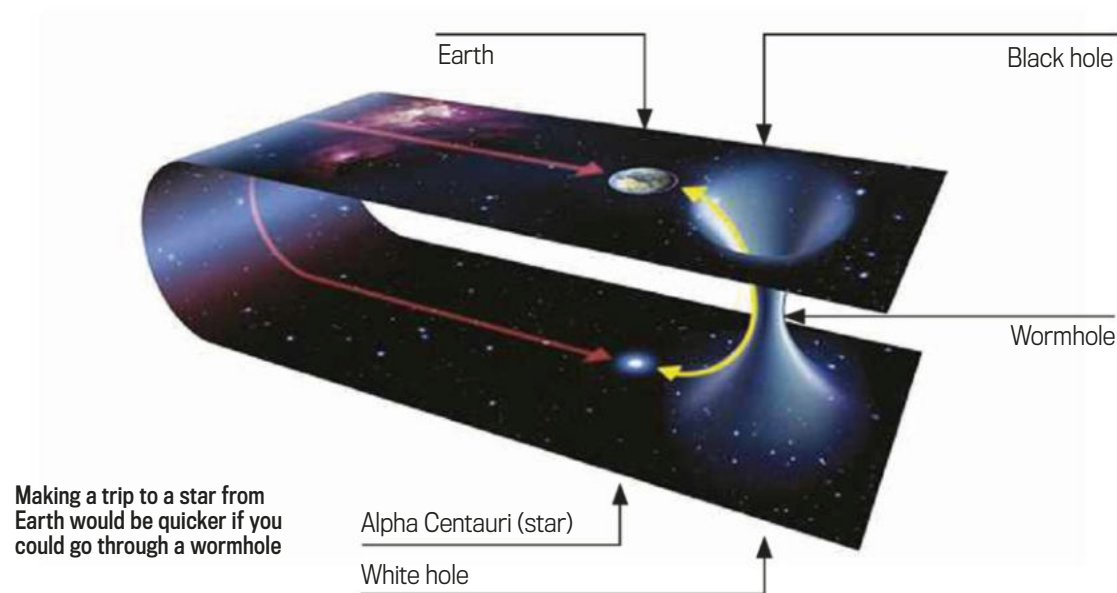
Go to sciencefocus.com/qanda/what and submit your answer now!

LAST MONTH'S ANSWER:

Dulcie Phipps correctly guessed fluorescing honeycomb coral

Q BRIAN WINNARD, RAINHILL

Could white holes exist?



A WHITE HOLES ARE not the 'opposite' of a black hole but in fact its 'time-reversal'. They are a feature of some solutions to Einstein's gravity field equations that predict the existence of 'wormholes'.

Wormholes consist of a black hole and a white hole that connect two points in the Universe at their 'event horizons'. However, mathematically, these wormholes appear to be highly unstable and would collapse as soon as they form. Furthermore, these solutions only apply to so-called 'eternal' black holes; ones that do not interact

with matter or lose mass through Hawking radiation. So any 'normal' black hole formed through gravitational collapse would not form such a wormhole (with its attendant white hole).

Unfortunately, no object has yet been observed (except for perhaps a few unexplained gamma-ray bursts) that could feasibly be a white hole. This has led most scientists to admit that white holes, although a useful and interesting theoretical possibility, could exist... but probably don't. **AG**

Q MILO MCLOUD, FROME

Can dogs laugh?

A THEY MAKE A sort of breathy, panting sound when they are playing. If you record this and play it back to other dogs, it appears to reduce their stress behaviours, such as barking and pacing, and increase their social behaviours, such as lip licking. Is that the same thing as laughter? Or is it just the dog equivalent of a broad smile? It's hard to say. Humans mostly laugh at verbal jokes and seeing other people fall over, neither of which have much effect on dogs. **SB**

Dogs don't laugh? Tell that to Scooby-Doo



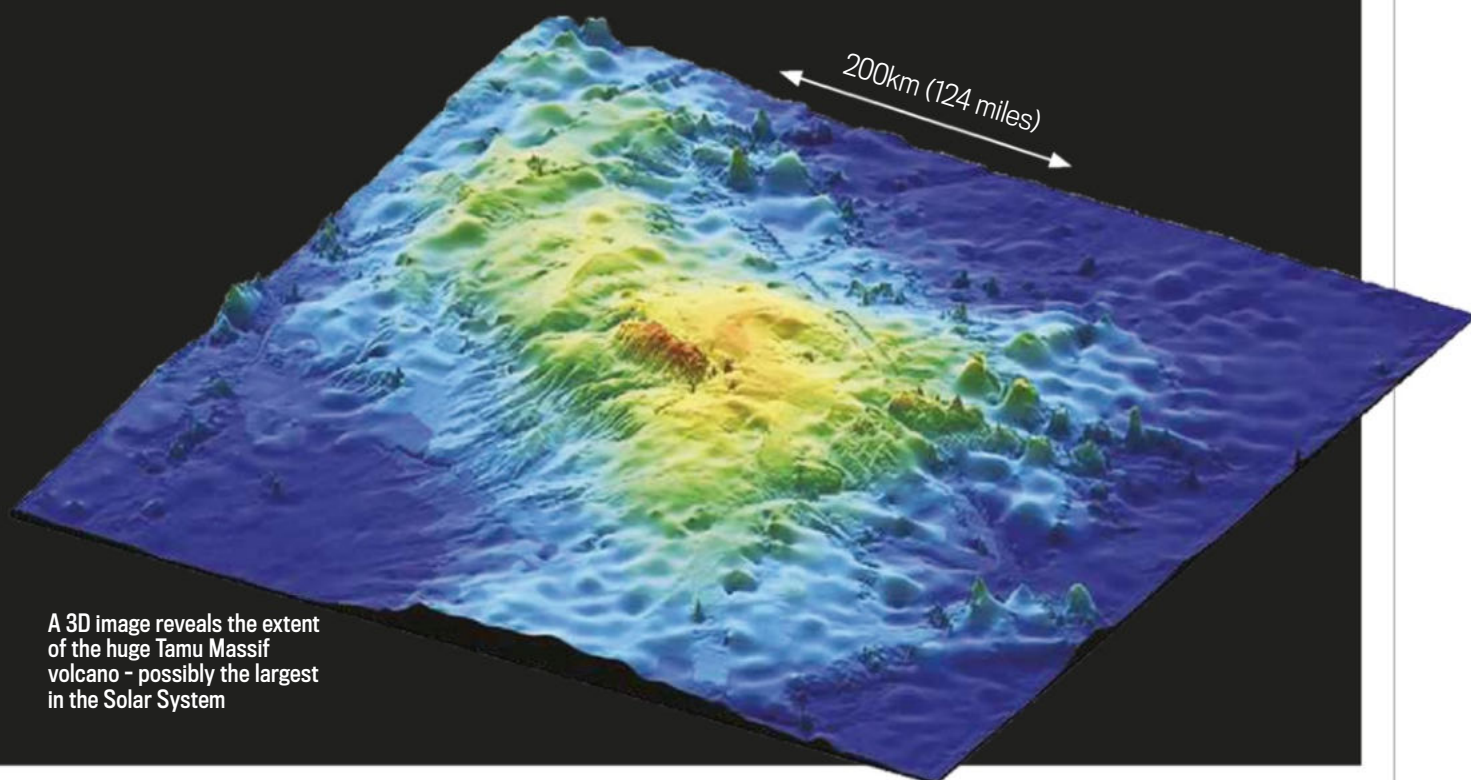
Q STELLA THOMPSON, LEEDS

What is the largest volcano in the Solar System?

A UNTIL RECENTLY the largest volcano in the Solar System was thought to be Olympus Mons on Mars. However, recent research has revealed that the Tamu Massif, a submerged shield volcano 1,600km (1,000) miles east of Japan, is actually larger. The Tamu Massif, which erupted between 130 and 145 million years ago, is about 640km (400 miles) wide and covers an area of about 190,000km².

In comparison, Olympus Mons is only 595km (370 miles) across, although it is thought to be 25 per cent more massive overall. **AG**

A 3D image reveals the extent of the huge Tamu Massif volcano - possibly the largest in the Solar System



Q FAUSTO STELLA, THAILAND

Why can't we trace the sender of an email?



A EACH EMAIL HAS an invisible header containing information like time stamps and routing information. It does not contain personal details like the sender's street name or phone number. However, the header does contain the originating IP address. That can narrow the origin down to a city or district, but seldom anything more specific and certainly not to an individual.

Online webmail services like Gmail are even more anonymous. A Gmail message, for instance, can only be traced back to a Google IP address. **GM**

Q SACHA REYNOLDS, LONDON

Is there any proof that echinacea stops you getting a cold?

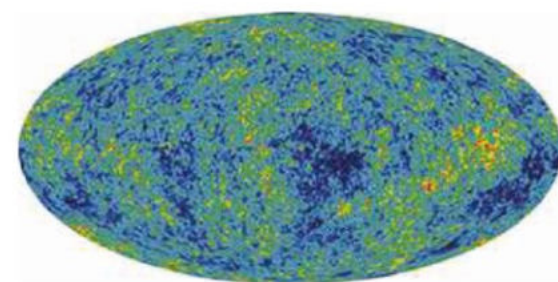
A THE CONSENSUS IS that it does not. A review by the Cochrane Library of 16 different trials that ran double-blind tests on various different echinacea preparations, found that there was no benefit in preventing colds, compared with taking a placebo. There is some evidence that once you catch a cold, echinacea might help reduce its duration by about a day and a half. The mechanism isn't understood and only nine of the 16 trials found a significant benefit, so the evidence is somewhat inconsistent. It may be that only some parts of the plant or some preparations have any effect. **LV**



It seems the common cold lives to see another day, although echinacea may reduce its duration

Q RJ WILSON, GLOUCESTERSHIRE

What does dark energy do?



It's hoped the radiation left over from the Big Bang (pictured) will help us investigate dark energy

A DARK ENERGY, IDENTIFIED by astronomers in the 1990s, acts like a form of anti-gravity. While its origins are unknown, observations reveal that it has a repulsive effect that is negligible at human scales but which gets stronger with distance, propelling the expansion of the Universe over the largest distances. **RM**

NEXT MONTH Over 20 more of your questions answered



For even more answers to the most puzzling questions, see the Q&A archive at www.sciencefocus.com/qanda

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Image of Ghost Nebula (vdB 141) shot using our new Aspen CG16m CCD camera
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IMAGING SYSTEMS

THE FUTURE OF GADGETS

TECHHUB

EDITED BY **DANIEL BENNETT**

THIS MONTH

BILL THOMPSON
The LEDs replacing Wi-Fi
p89

JUST LANDED
Tado° heating system
p90

ULTIMATE TEST
Digital-Analogue
Converters
p93



ON THE HORIZON

STEAM MACHINES

MULTIMEDIA AND
GAMING SET-TOP BOX

WORDS: **NEON KELLY**

valvesoftware.com
(prices TBC)

THE WORLD'S most influential games developer is launching its own range of living room hardware. Valve is the undisputed king of PC gaming, an innovator without peer. In addition to creating genre-defining titles like *Half Life*, *Portal* and *Team Fortress 2*, Valve is the company that brought us Steam – a software delivery platform that set the blueprint for downloadable gaming. Released in 2003, the Steam service now boasts 65 million users, the same number

of people that populate the UK. And now Valve is about to move into hardware.

Rumours of a Steam Box have been circulating online for years, shrouded in the same air of mystery that pervades everything Valve does. The company is promising not one but an entire series of Steam Machines: compact yet powerful gaming computers, designed for your living room, built using beefy chipsets from the likes of Nvidia, Intel and AMD. The details will vary from model to model, but the common link between them is

Steam OS – a purpose-built, open-source operating system, based on Linux.

Strictly speaking, there's not much to separate Steam's machines from the gaming computers that are already on the market. But while the deep end of the PC pool is largely the domain of hardcore enthusiasts, accessibility is the key here. If you want to dabble in the dark arts of PC gaming without fretting too much about the fiddlier technicalities – such as building your own computer – a Steam Machine will offer an easy point of access. ➔

The Steam Machine's controller swaps thumbsticks for trackpads to provide greater input precision



This formula worked for Google, which built the Android smartphone operating system and let hardware manufacturers concentrate on what they were good at: making machinery. The result was a gamut of smartphones more user-friendly than anything offered by Nokia and BlackBerry and more affordable than the iPhone.

Valve's hoping its parallel approach, offering up the Steam Operating System, and a range of hardware from different manufacturers, will mirror the success of Android. And by remaining open source, like Google's software, it'll eventually bring in the largest selection of streaming TV services, games and apps of any smart TV hardware available.

In a move that will rattle the cages of Microsoft and Sony, Valve has also unveiled a new controller. It resembles a traditional twin-stick pad, but with circular touch-sensitive trackpads in place of the usual thumbsticks. In addition to haptic feedback (vibrations that give you a physical response to the action), the pads are said to offer unprecedented levels of precision. The promise is clear: the comfort of a console meshed with the finesse of a PC.

"I'm impressed by the innovation that they've shown with the controller," says Byron Atkinson-Jones of Xiotex Studios, an independent games developer. "It gives me real hope that we haven't yet come to an evolutionary dead end in terms of controller design."

Despite his enthusiasm for the new controller, Atkinson-Jones sees the move into hardware as a brave one for Valve. "Steam is a relatively unknown brand for the mass market, so whether they can get enough interest outside of their traditional PC gamer customers remains to be seen. Consoles aren't just devices to play games on – they're a service, and a bad experience can put people off."

In the eyes of existing PC users, Valve is one of the most trusted names in the business. If they can extend this expertise to living room entertainment it could transform what we think of as a set-top box. It may mean that we could finally have one box that really does do it all.

NEON KELLY is a freelance gaming journalist based in London

TECHOMETER

WHAT'S HOT

HELIUM-FILLED HARD DRIVES

While air can seem pretty thin to you and me, it can be relatively dense. In fact, it's so thick that Western Digital is now replacing it with lighter, thinner helium gas inside its hard drives. As the disks spin round inside the drive housing they experience less resistance from the helium than they would with air, and are therefore more efficient. This means more disks can be stuffed into the same space, ballooning storage by up to 50 per cent.



WHAT'S NOT

NFC PAYMENT CARDS

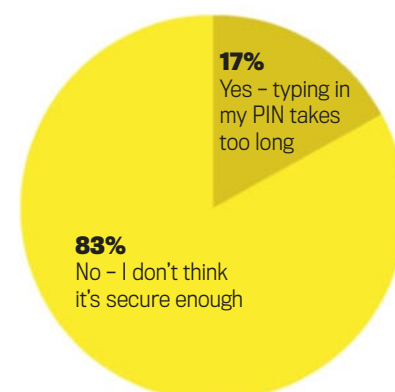
New NFC bank cards let you tap your card on special readers to pay for items under £20 without having to enter your pin. It's convenient, but researchers from the University of Surrey aren't certain it's secure. They rigged up a system that could be carried in a backpack and could take payments from NFC cards at a distance of up to 45cm. The students could

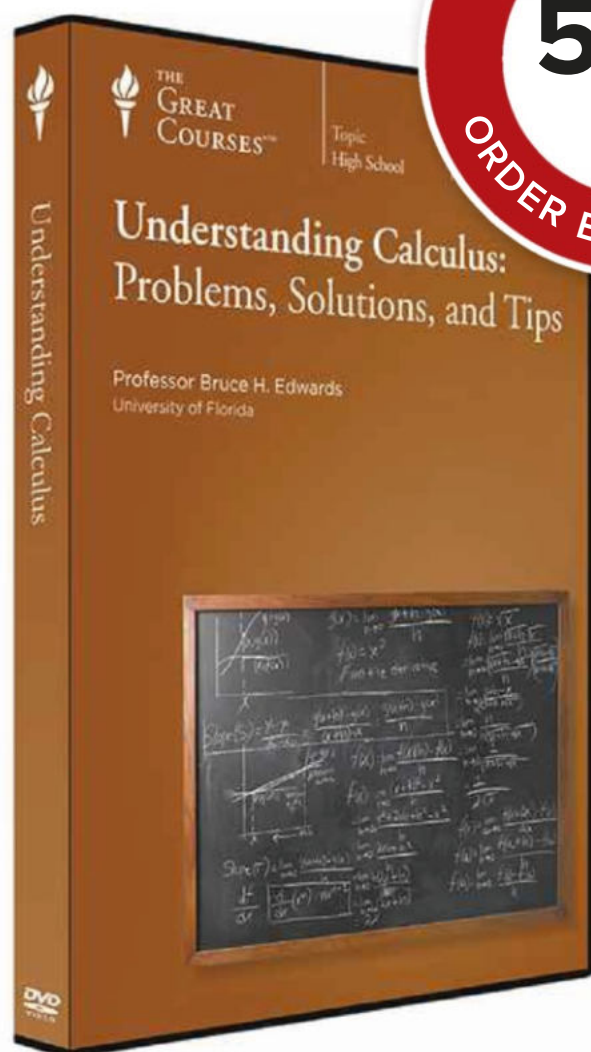


skim money off shoppers' cards just by walking past them.

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5. An Introduction to Continuity
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7. The Derivative and the Tangent Line Problem
8. Basic Differentiation Rules
9. Product and Quotient Rules
10. The Chain Rule
11. Implicit Differentiation and Related Rates
12. Extrema on an Interval
13. Increasing and Decreasing Functions
14. Concavity and Points of Inflection
15. Curve Sketching and Linear Approximations
16. Applications—Optimisation Problems, Part 1
17. Applications—Optimisation Problems, Part 2
18. Antiderivatives and Basic Integration Rules
19. The Area Problem and the Definite Integral
20. The Fundamental Theorem of Calculus, Part 1
21. The Fundamental Theorem of Calculus, Part 2
22. Integration by Substitution
23. Numerical Integration
24. Natural Logarithmic Function—Differentiation
25. Natural Logarithmic Function—Integration
26. Exponential Function
27. Bases other than e
28. Inverse Trigonometric Functions
29. Area of a Region between 2 Curves
30. Volume—The Disk Method
31. Volume—The Shell Method
32. Applications—Arc Length and Surface Area
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THE NEXT BIG THING

LIGHT: THE NEW WI-FI

USING RADIO waves to carry binary data instead of analogue-encoded sound or images is pretty standard these days, and everyone using a digital television or radio, mobile phone or wi-fi-connected computer is doing just that.

But a new approach promises faster and more reliable data transfers for a wide variety of uses. Like fibre-optic systems, it uses visible light, but the technology is different.

Invented by Professor Harald Haas at the University of Strathclyde, Glasgow, 'Li-Fi' uses micro-LEDs operating in the visible spectrum to transmit data at up to 3.5 gigabits per second (Gbps) by making the bulbs flicker - that's three times what current Wi-Fi can offer.

The flickering is at a frequency too high to be seen by the human eye but it can be detected by a photodetector chip, and thus used to deliver very fast data rates. What's more, you can use different coloured LEDs to transmit multiple bands at the same time, and the higher frequencies involved mean that there's a lot less interference between these bands than with radio or microwave frequencies.

The result is speeds in the lab of up to 10Gbps using red, green and blue LEDs in parallel, and Professor Haas hopes that these will translate into commercial products that can deliver similar speeds.

After some years of development it's on the

verge of commercial exploitation and 'Li-Fi' (aka VLC - Visual Light Communications) could be coming to your home or office soon.

One area where it could appear is toys - Disney has a whole research programme dedicated to what it calls 'LED-LED communication'. Picture a Mickey Mouse doll in his *Sorcerer's Apprentice* garb that follows the gestures of your magic wand.

The technology might also be used for traffic management. LED traffic lights could communicate with your car to help you brake in time. There's also a real possibility that visible light LEDs could solve the internal navigation issues that bedevil maps and augmented-reality systems,

replacing inaccurate GPS signals with precise coordinates transmitted from buildings.

Even one of the system's disadvantages is really a bonus, says the team developing it. Unlike the wi-fi microwaves, visible light doesn't go through walls, making it harder for people to 'borrow' your internet connection and reducing interference.

It all sounds great, but it's only been tested in the lab so far, so I think I'll wait to see if VLC is more than a flash in the pan.



BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service



COMING SOON

3 MONTHS

NVIDIA TEGRA NOTE

Nvidia's TEGRA chipsets have been powering incredible graphics on mobile phones in recent years, so a dedicated tablet from the company is worth keeping an eye out for. Nvidia.com



+ Windows Phone 8.1

The updated Windows mobile OS is reported to feature a Siri-like virtual assistant and better app support. Windowsphone.com

+ Samsung Galaxy S5

Google's Nexus 5 may be the new benchmark for Android phones, but Samsung's Galaxy always introduces new innovations. Samsung.com

6 MONTHS

GOOGLE NEXUS GEM

Tech you can wear will be bigger than ever in 2014. No manufacturer has yet made a watch we'd want to buy, but one with the Google Now diary system that works with its smart glasses could get us reaching for our wallets. Google.co.uk/nexus



+ Alcatel One Touch Flip Cover

This smartphone has a colour screen and a second e-ink screen. This way your phone uses very little battery if you're reading or just checking the time. Alcatelonetouch.com

+ Whistle

Keep an eye on your dog's health with this canine activity tracker. It'll keep an eye on how much exercise, rest and play Fido is getting and create charts based on the data. Whistle.com

9 MONTHS

SKULLY

This prototype helmet will offer bikers a HUD to warn riders when an object enters their blindspot and shows them the view from behind. Skullyhelmets.com



+ Rasperry Pi Monitor (HDMIPI)

The credit card-sized, £22 computer has created a mini-revolution, despite lacking an affordable screen. That's about to change as a UK-based start-up is bringing out a 9in HD monitor for the Pi for just £65 later this year. Raspi.tv

+ Intel Gesture Control

Intel will be bringing its gesture control system to laptops and PCs this year, so most new computers will have some form of motion-control by the end of 2014. Intel.com

JUST LANDED: TADO°

HIGH-TECH HEATING

As energy companies hike up their prices by another 10 per cent this winter, **Daniel Bennett** investigates a cheaper, smarter way to heat your home

What is it?

This white box promises to cut your heating bills by up to 25 per cent. The tado° system works in two ways. First, it connects your central heating and your broadband so that you can control your thermostat with your smartphone. This way you'll be able to monitor and set the temperature wherever you are. Second, by connecting to tado°'s network, it can use smart algorithms to optimise how your home is heated, and tell you exactly what it will cost you.

What will it do?

The app will monitor when you leave home, so the heating's never left on while you're out. You can also tell it your daily schedule so that the heat drops while you're asleep and climbs when it's time to get up. It'll track other variables too, such as how long it takes to bring your home up to the specified temperature. By compiling these and other factors, the tado° calculates the cheapest heating pattern for you and your home.

Will it work with my old thermostat, programmer and boiler?

Most likely, yes. A tado° kit can be used to replace, or work with, most existing central heating units in the UK. If you're installing it yourself, the online set-up guide lists dozens of thermostat manufacturers



whose units are compatible with tado°.

How easy is it to install?

The hardware is designed to be installed by anyone. Disconnecting your own heating controls will be intimidating though – especially if you're planning on doing it during winter! But detailed, concise instructions and clever packaging make it about as simple to put together as flat-pack furniture. If, like us, you find any anomalies during set-up (we found six wires coming out of our wall rather than three), tado°'s friendly customer support service is only a phone call away. If this all seems too

daunting, there will be an installation service option.

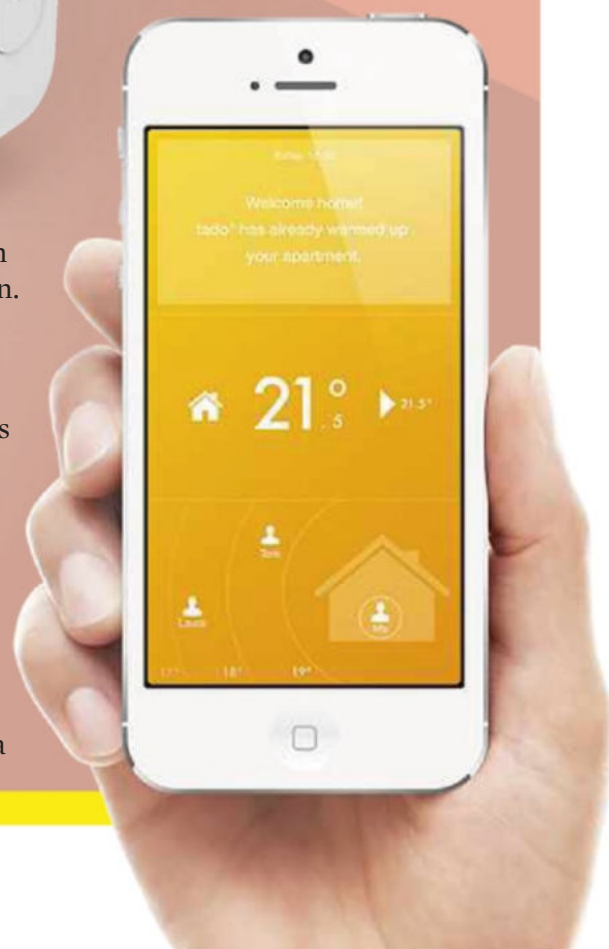
Does it really save you money?

Most current thermostats and programmers are blunt instruments when it comes to controlling your heating. They're often placed in the least used room in the house and have difficult-to-fathom controls. The tado°, by comparison, is a

precision tool. After setting your initial parameters – how warm you like it (to within 0.1°C) and when you get up and go to bed – it'll take care of the rest. And if you want to rethink your settings, the app will give you instant feedback as to how the boiler has been working over the past day, week, month or even year. While £249 is a big initial spend, it could pay for itself within three years, and after that it'll help soften the blow of ever-increasing gas prices.

TADO°
WWW.TADO.COM, £249 (OR
£6.99 A MONTH TO RENT)

DANIEL BENNETT is the reviews editor of *BBC Focus* magazine





APPLIANCES OF SCIENCE

1 FILTERED TIPS

James Dyson must hate housework. First he got rid of those vacuum cleaner bags you had to change every few weeks, and now his new Cinetic cyclone technology means you don't need to clean or replace dusty filters. This new vacuum cleaner has 54 small cyclones to maintain airflow and each of these has a special oscillating tip that prevents particles from gathering together and clogging up the system.

Dyson Cinetic
Dyson.co.uk, price tbc

2 SMELL YOU LATER

Ever wanted to share a smell with someone? No, us neither. But that hasn't prevented Vapor Communications from coming up with a device that sends scents. You start with an app that lets you "compose" your own smell: a smidgen of caramel here, a whiff of espresso there. You then send the olfactory information of your composition to someone with an Ophone device that will create that same smell.

Ophone
Vaporcommunications.com, price tbc

3 GREEN LIGHT

Meet the future of light bulb technology. The Nanoleaf offers the brightness of a standard 100W bulb but uses just 10W of power. It does this with an LED array that operates at a far lower temperature than a typical light bulb. In addition, they're made without using mercury or lead so they're friendly to Planet Earth. It's simply a bonus that they look like something out of *Blade Runner*.

Nanoleaf
thenanoleaf.com, \$35 (£22) plus P&P

4 SHAPESHIFTER

There isn't always an easy or secure way to store your helmet after a bike ride, which is why Jeff Woolf, a British inventor, has come up with the Morpher – a foldable helmet that collapses into a package small enough to fit into most bags. The Morpher's convenience doesn't compromise its protection, though. Its manufacturer, Strategic Sports, says the helmet exceeds most safety standards.

Morpher helmet
Morpherhelmet.com, \$110 (£69) plus P&P

5 PLANT WHISPERER

We've killed so many houseplants (well, desk plants) at *BBC Focus* that there should be a law against us buying anything leafy. But coming to the rescue of flora everywhere is the Flower Power, a sensor that sits beside the plant to monitor how much sunlight and water it's getting and how fertile the soil is. It checks these readings against a database of over 6,000 plants and tells you how to help your green friend.

Parrot Flower Power
Parrot.com, £49.99

6 CLEAN UP BOT

iRobot, the creators of Roomba, the robotic vacuum cleaner, have now built a mechanical dogsbody to tackle mopping. But instead of randomly traversing your floors like Roomba, the Braava relies on a 'Northstar Navigation Cube' for direction. This projects a signal onto the room's ceiling that Braava can use to track and plot its route. Now iRobot just needs to build a device that will do the laundry too.

iRobot Braava
irobot.com, from £199

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ULTIMATE TEST **AUTHENTIC AUDIO**



Digital-to-Analogue Converters take your MP3 music tracks and make them sing. **Dan Bennett** tests four

What is a DAC?

A digital music file is made up of a stream of 1s and 0s. To turn this into sound, the data needs to be converted into an analogue electrical signal that can drive a speaker. That's where a DAC – a Digital-to-Analogue Converter – comes in. Like reading a book aloud, it takes written information and turns it into sound. The skill is getting the pronunciation and inflection just right.

How do they work?

To convert the data to an analogue wave, a DAC has to do three things. It must accurately read the data, generate the sound at precisely the right time and then flesh out the wave between each digital point of information. Your PC already does this, but an external USB DAC will override your computer's soundcard.

Why should I buy one?

If you've got a high-quality digital music library and some high-end speakers, then your PC might be the weak link in the chain. Plus, if you've always felt like your CDs and MP3s are missing the warmth of old vinyl records, then this will be the next best thing to getting the decks out. A great DAC will make the sound more accurate and more lifelike than ever.



MERIDIAN EXPLORER DAC

Meridian-audio.com; Price: £249

➔ TO MAKE A DAC the size of a Snickers bar, Meridian Audio has taken some of its high-end audio equipment and stripped it of everything but the bare essentials. It takes all of 20 seconds to set up: simply connect the USB to your Mac or PC (Windows' users will need to download a driver), plug your headphones in and you're away.

Unlike the other devices here it draws all the power it needs from its USB, so there's no need for a plug. The case is pitted with a series of three light indicators, which tell you the quality of the music you're putting through it – all three lit up means you're using it to its full potential (playing a lossless audio file).

Thankfully you don't even need to use the best possible music files to get something out of the Explorer. Stream a heavily layered song like *Zebra* by Beach House through Spotify and it opens up the sound, adding warmth and depth. Indeed, as you go up through each standard of file quality, the music gains more and more breadth. It has to be said, though, that the difference isn't as immediate as the other DACs on test. The Explorer is a simple, capable device that's a great place to start if you're new to DACs. It will work with speakers as well as headphones, but lacks the ultimate depth of sound offered by the higher end models.



NAIM DAC-V1

www.naimaudio.com; Price: £1,250

AT £1,250 THE Naim costs more than most PCs, but with this DAC you're buying more than just an upgrade: this is the device you buy to go from great to perfect. Sat next to some very special DALI speakers (used to test all four devices) and an amp, this really brings music to life. It gave new dimensions to otherwise overplayed classics like Hendrix's *All Along The Watchtower* and drew out the quiet, low-end bass favoured by bands like The xx. Each instrument had more definition than with any other DAC on test. I enjoyed revisiting the xx album, listening all the way through to hear the way the frail bass and raw vocals became stronger and clearer.

At the rear there's every kind of input and output you could ask for, so you can connect several devices to the Naim at once (a Blu-ray player alongside your PC, for example). It's futureproof too. The DAC can handle all the file qualities you'd expect and more. It's even capable of processing a 24-bit/384kHz music file, a format that won't be widely available for some time yet, so you're unlikely to need an upgrade any time soon. The in-built headphone amp is a nice bonus too. The functional design will please audiophiles, but others might hanker after something a bit more elegant. But that's a minor foible you'll forgive soon after turning it on.



WHAT MUSIC SHOULD I DOWNLOAD?

Getting hold of the best quality music isn't as simple as picking up a CD. There are dozens of formats and variations, so which should you buy?

■ = 2.5MB

MP3

This is the most common format. The quality of an MP3 – measured in kbps, the amount of kilobits transferred per second – can vary hugely, but whether you're taking music off a CD ('ripping') or buying it online, opt for 320kbps. At 4MB per file, it's a fair compromise between file size and sound quality.



AAC

Made popular by iTunes, the AAC file (Advanced Audio Coding) offers better compression. This means your music library will take up less space on your hard drive. Because it's slightly less common you could come up against a media player that might not be able to play it.





ARCAM irDAC BEST BUY

Arcam.com; Price: £400

ARCAM HAS A long, successful history of bridging the gap between digital music and high-end audio, and this tradition is evidenced in the irDAC. Its small, discreet case will look the part in most living rooms and it comes with a simple remote if you want to tuck it away out of sight. All the cables you need to get it up and running are thrown in, and the set-up guide is unimposing. A nice added touch is the iPod input, making it easy for anyone to just plug into your system and let the irDAC do its magic with minimal fuss.

It worked wonders with a low quality stream of Elbow's *One Day Like This*, adding a texture to the strings and a crispness

to the drum cymbals. Listening to something a little more restrained at a higher bit-rate like James Blake's *Retrograde* demonstrated how good the irDAC's timing is: the bare vocals and big bass sounded incredibly precise.

At a third of the price of Naim's V1, this DAC is perfect for all but the most devoted audiophiles. It's worth noting that it works seamlessly with Arcam's Bluetooth receiver if you want to wirelessly stream music to your sound system, with no loss of quality.

There's only one slight drawback. Of the four, this is the only device without a headphone amp, which would have been a nice addition.



AVG FILE SIZE

APPLE LOSSLESS

If you're determined to use iTunes with lossless music, then Apple's lossless format (ALAC) is the way to go. It's similar to a FLAC file, but slightly less compressed. A whole album can be over 500MB in size, so make sure you've got plenty of hard drive storage.



WAV AND AIFF

These are completely uncompressed formats, WAV made by Windows, AIFF by Apple. They're exact copies of what came out of the recording studio and are as close as you'll get to the original audio. A single track can be up to 100MB in size.



AUDIO LAB M-DAC

Audiolab.co.uk; Price: £599

MORE OFTEN THAN not I find myself testing black boxes, so it's nice to come across something that looks a bit different. In fact, the Audio Lab M-DAC looks so smart that it's the only device of the four I'd actively put on display. As you'd expect at this price, there are as many inputs and outputs as you're likely to need. There's also a range of filters on offer, but with names like 'Transient Optimal' we struggled to pinpoint the difference, though I'm sure an audio engineer could tell us otherwise.

Of the four devices we tested, the M-DAC generated the most clinical sound. After using Arcam's irDAC, this left us a little cold. That said, the accuracy will appeal to

professionals. Tracks bustling with effects and instruments, like Grizzly Bear's *Sleeping Ute*, are remarkably clear and precise – I actually picked out a triangle being struck that I had never noticed before. Inside its smart aluminium casing there's also a very good headphone amp, making it ideal if you just want to invest in a single box to get more out of your music.

All in all its digital conversion is hard to fault, but it's amongst some tough competition at this price point.



DAN BENNETT is the reviews editor of BBC Focus Magazine

FLAC

A lossless file like a FLAC is closer to the original music than an MP3. The data isn't nearly as compressed as with an MP3 – a file can be 36MB in size – but it will provide your DAC with more information to work with.



THE NATURE OF FIRE

BY ALEXANDER HELLEMANS

Chemistry underwent a revolution at the end of the 18th Century, brought about by finally disproving old ideas about fire

F

IRE IS ONE of the oldest forms of technology. Hearths found in the Swartkrans Cave in South Africa show that early humans, *Homo erectus*, used fire a million years ago. Its nature was pondered in Antiquity by Greek philosophers, and Heraclitus

of Ephesus (about 540-475 BC) called it the 'primary substance'. Empedocles (about 492-435 BC) was one of the first to believe that matter was made up of four primary substances or 'elements': earth, water, air and fire. Aristotle (384-322 BC) adopted the concept of these four elements, each of which was endowed with two qualities. Earth was cold and dry; water, cold and wet; air, hot and wet; and fire, hot and dry.

The description of the world supported by Aristotle was qualitative, based on metaphysical or philosophical views. Concepts were directly linked to human experience or expectations. This Aristotelian view of the world survived for most of the Middle Ages, but began to be challenged in astronomy and physics in the 17th

Century. Galileo Galilei and Isaac Newton changed science by linking scientific concepts to mathematical reasoning. Science became quantitative, not just qualitative. Mathematics became a scientific tool; measurements were taken from experiments and observations.

CHEMICAL QUEST

But one subject escaped this revolution: chemistry. Newton, like many of his contemporaries, viewed it as more art than science. Indeed, he was involved with alchemy and the search for the 'philosopher's stone', a substance said to turn lead into gold. He never thought of applying the techniques that had made him so successful, measurement and mathematics, to his chemical experiments.

The concept of Aristotle's four elements remained largely unchanged during the 17th Century. But there was a new theory about matter from alchemist Johann Joachim Becher. He thought that combustible matter burned because it contained an oily

and sulphurous earth, which he called 'terra pinguis'. This constituent was renamed 'phlogiston', from the Greek 'to set on fire', by Becher's student Georg Stahl. Phlogiston was forced out of things when they burned, producing fire. Substances containing phlogiston were said to be phlogisticated and they dephlogisticated when burned. Things like wood, charcoal, phosphorus and sulphur contained a lot of phlogiston and therefore burned easier.

Stahl's ideas about what happened to the phlogiston when released into the air were quite original: he said it caused lightning, which excited the air. The excited air subsequently collapsed, which we hear as thunder. The lightning theory was wrong – today we know that lightning consists of channels of ionised (excited) air, through which an electric discharge passes. A vacuum is created, which causes nearby air to rapidly expand and contract, producing thunder.

Stahl also argued that phlogiston was indestructible, and was continuously being recycled. Besides lightning, it was also



Fire was one of four elements, alongside, air, earth and water, that the Ancient Greeks believed made up everything around us

> IN A NUTSHELL

Fire is one of the oldest tools but its real nature eluded us for thousands of years. It wasn't until the late 18th Century that the idea of fire being made from 'phlogiston' was overturned by the emerging science of chemistry.

→ present in clouds and rain and was taken up by plants and animals. The strongest argument for its existence was that phlogiston explained many of the processes studied by chemists during the 17th Century. It would explain why ashes, obtained by burning wood, would not burn – the wood had been left without phlogiston.

The phlogiston theory was thought to explain not only combustion but also the well-known process of producing metals from ores. When ore was heated in the presence of charcoal, the charcoal gave off phlogiston while turning into ashes. The phlogiston was then absorbed by the ore, turning it

into a metal. That meant a metal was a combination of two components: phlogiston and a substance called calx (see 'Need to know' on p97). The reverse process, the rusting of metals, would be explained by the release of phlogiston. Rust didn't burn, therefore it didn't contain phlogiston.

Stahl's views on phlogiston became widely accepted during the 18th Century. The theory, though, was flawed. When wood is burned, the resulting ash is lighter than the wood before combustion. Sulphur, when burning, disappears entirely. It was thought these substances must become lighter due to the loss of

phlogiston. Metals too were thought to lose phlogiston in the process of combustion, yet they became heavier. Moreover, heating a calx with charcoal also resulted in a loss of mass when a metal was formed. This despite phlogiston supposedly being added.

A solution to this paradox came from the French surgeon Gabriel Venel (1723-75), who was also interested in chemistry. He suggested that phlogiston had a negative weight. Adding phlogiston to a metal formed by heating calx with charcoal would therefore make it lighter, as shown by experiment.

The problems for phlogiston were only just beginning, however. If a

THE KEY EXPERIMENT

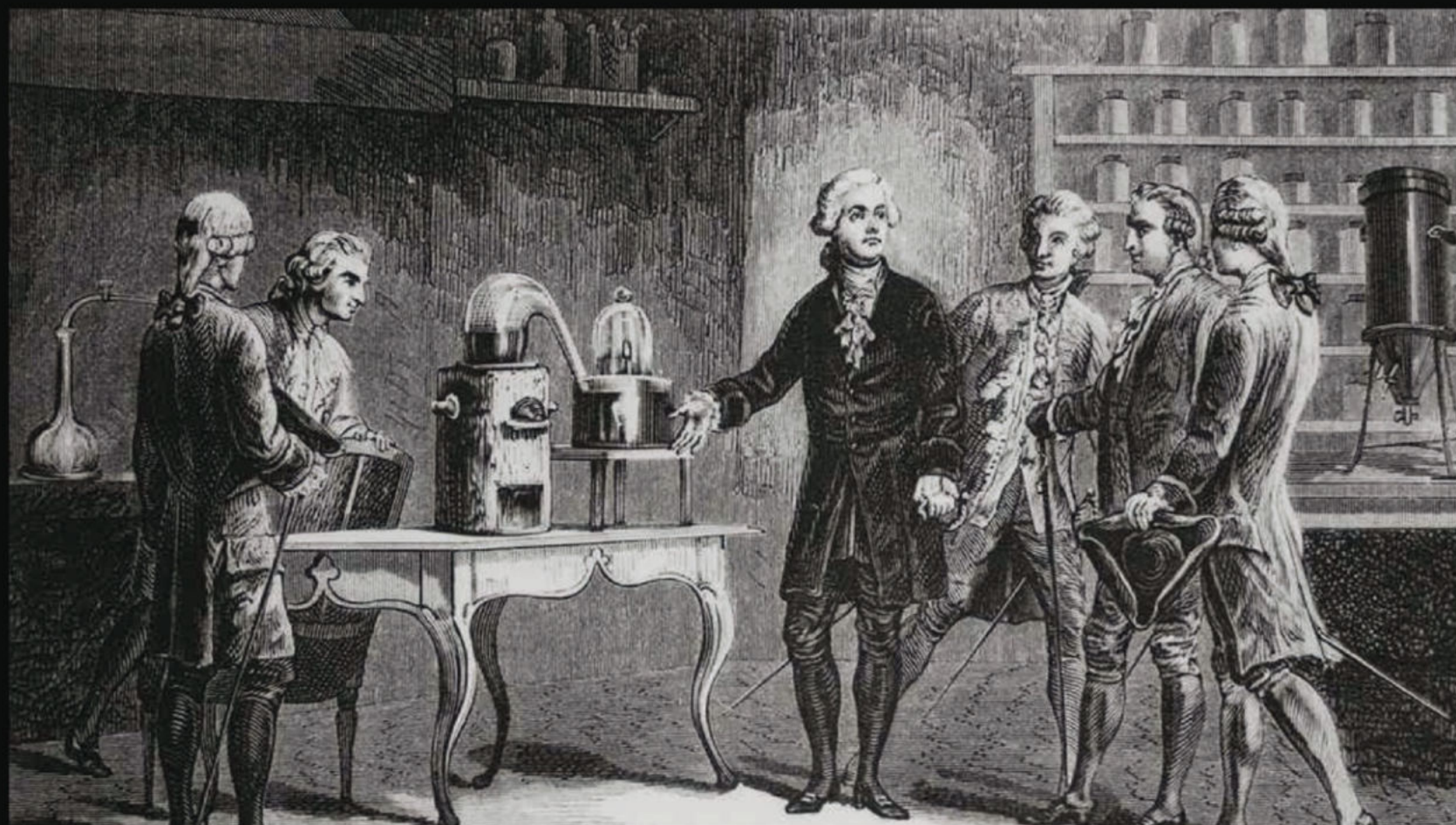
An ingenious set of apparatus enabled Antoine Lavoisier to disprove the concept of fire-causing 'phlogiston' and discover a crucial ingredient of air: oxygen

IN 1774, ANTOINE Lavoisier decided to test his views on the combustion and reduction of a single metal. He filled a flask called a 'matrass', which had a long curving neck like an elephant's trunk, with four ounces of mercury and placed it on a furnace. The mouth of the matrass was covered with a bell jar placed in a trough of mercury. When Lavoisier heated the metal till it was nearly

boiling, a reddish crust of calx started floating on its surface.

After 12 days, when no more calx was forming, the level of mercury inside the bell jar had risen higher – the calx was absorbing something from the air inside the flask. Lavoisier calculated that one-sixth of the air had been absorbed. The remaining five-sixths of the air, which he called 'azote',

extinguished a candle and mice could not live in it. Now, Lavoisier wanted to reverse the reaction. He skimmed off the calx from the mercury and heated it. The calx underwent reduction to liquid mercury, giving off the same amount of air as it initially absorbed. This air caused a burning taper to burn brightly and the mice loved it. He called it oxygen.



Antoine Lavoisier demonstrates the experiment that revealed the composition of air to fellow scientists; in doing so the idea of phlogiston was turned on its head

material undergoes combustion inside an airtight vessel, the process will eventually stop. The reason, according to Georg Stahl, was that air could take up only a limited amount of phlogiston and became saturated. However, this did not explain why pressure in the vessel also decreased. If you've ever seen a boiled egg placed in the mouth of a milk bottle in which a candle is burning, you'll have witnessed the egg being dramatically sucked into the bottle. If phlogiston really was given off by burning material, the pressure in the bottle should increase.

The discovery of different types of air, later identified as different gases, complicated the issue still further. Chemists began experimenting with different materials, and testing the gases given off during combustion or chemical reactions. They checked whether different kinds of air could sustain a burning candle, or keep a mouse alive. For example, in 1755 the English chemist Joseph Black found that if you react sulphuric acid with chalk or heated limestone, you obtained 'fixed air', in which candles would be extinguished or mice would not survive. Known today as carbon dioxide, it turned limewater milky.

INFLAMMABLE AIR

In 1766, the English chemist Henry Cavendish (1731-1810) reacted zinc, iron and tin with acids, and collected the gas that came off. He called it 'inflammable air' because it readily ignited, and wrongly concluded that the gas must be phlogiston (it was in fact hydrogen). This again led to a contradiction. Phlogiston was supposed to stop combustion, but Cavendish found that it did just the opposite by burning itself.

Nearly a decade later, the English chemist Joseph Priestley made a surprising discovery. By heating red oxide of mercury (a calx), Priestley found that it expelled 'air' with different properties than expected. Instead of extinguishing a candle, the candle started burning very brightly, and mice lived twice as long in the trapped air than 'common air'. Priestley believed this 'pure air' caused candles to burn longer because it was free of phlogiston. He called it dephlogisticated air. It would also explain respiration. When breathing, it was believed that phlogiston was exhaled, which left 'common air' →

CAST OF CHARACTERS

Throughout the 17th and 18th centuries, physicians and chemists pondered the make-up of fire



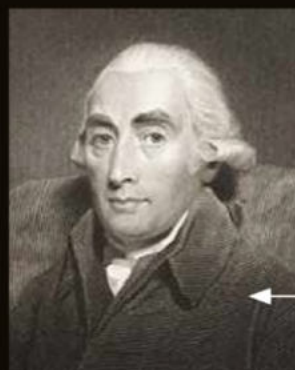
Johann Joachim Becher

(1635-1682) was a German physician and polymath who was appointed Professor of Medicine at the University of Mainz in 1657. He published a series of books on topics ranging from politics to the sciences. Settling in London in 1682, he wrote three books on chemistry.



Georg Ernst Stahl

(1660-1734) – a German physician and student of Becher, he started teaching at the University of Halle. He adopted an animistic approach to medicine, associating physiological processes, such as involuntary motion in animals, with the soul. Later he became the physician of King Friedrich I of Prussia.



The Scottish chemist **Joseph Black**

(1728-1799) made fundamental contributions to chemistry, introducing quantitative methods in experiments. His research with latent heat, the heat required to melt ice or convert water into steam, were the first steps in what later became known as thermodynamics.



Joseph Priestley

(1733-1804) was a Unitarian minister and amateur scientist. Encouraged by Benjamin Franklin, Priestley experimented with electricity. He investigated gases and dissolved 'fixed air' in water, creating soda water, and independently discovered oxygen.

Because of his sympathy for the French Revolution, Priestley had to move to the US in 1794.



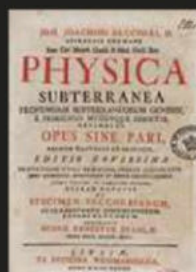
Called the father of modern chemistry,

Antoine-Laurent Lavoisier

(1743-1794) financed his research by running a private tax-collecting company. He was the first to develop the concepts of chemical elements and compounds. Besides oxygen and nitrogen, he identified and listed several other elements. He was executed during the Reign of Terror after the French Revolution.

TIMELINE

Phlogiston theory became so entrenched among scientists that it took nearly 100 years to overturn



Johann Joachim Becher introduces the concept of 'terra pingus' (oily earth) as the substance that's contained in materials and causes fire in his book *Physica Subterranea* (Subterranean Physics).

1669

1697

Georg Ernst Stahl introduces the concept of phlogiston, a substance that causes fire and rusting, based on Becher's idea of oily earth.

1755



Joseph Black discovers 'fixed air', now known as carbon dioxide. It extinguishes candles and does not support life.

1766

Henry Cavendish reacts metals with acids, producing hydrogen - he called it 'inflammable air', equating it to phlogiston.



1774

Joseph Priestley, during a meeting in Paris, explains to Antoine Lavoisier how he prepared dephlogisticated air (oxygen) by heating calx of mercury.

1778



Lavoisier reports the result of an experiment involving the oxidation and reduction of mercury, rejecting the idea of phlogiston. Air consists of a smaller amount of oxygen and a larger amount of nitrogen.

→ saturated. Priestley's pure air, in contrast, was good for breathing because it was free of phlogiston.

All of this testing of gases by the English chemists was being closely followed from across the Channel, where Frenchman Antoine-Laurent Lavoisier was growing suspicious of the phlogiston idea. He decided to look into it by setting up his own chemical laboratory. His wife, Marie-Anne Pierrette Paulze, became his laboratory assistant, taking notes and translating the English reports. Lavoisier conceived of a series of experiments to investigate whether the 'air' involved when things burned was the air we breathe or a special kind of air, like the 'fixed air' discovered by Joseph Black. Finally in 1774, Lavoisier met Priestley for dinner in Paris and briefed him on his own research. The stage was set for Lavoisier to repeat the Englishman's experiments, and the results would change the course of science.

PHLOGISTON'S DEMISE

One experiment convinced him that the idea of phlogiston being given off during combustion was wrong. He sealed tin inside a flask and heated it by focusing sunlight on it with a large magnifying glass. He weighed the flask before and after combustion, and found that there was no change in weight. When he opened the flask, he noticed that air rushed in, and that now there was a small increase in the weight of the flask. He realised that the tin, turning into a calx, had absorbed something from the air in the flask. It had not emitted phlogiston.

Lavoisier then set out to see what happened if a calx is heated in the presence of charcoal - a process known as reduction. According to existing scientific views, this would transfer phlogiston from the charcoal to the calx, turning it into a metal. Lavoisier placed a piece of litharge (a calx of lead) on a small pedestal in a basin of water. He covered the pedestal with an inverted bell jar, and heated the calx with sunlight and a magnifying glass. He saw the water level inside the bell jar start to go down, indicating clearly that the calx, turning into lead, was emitting some kind of air. When he tested it, he found that it would extinguish a candle. It had to be 'fixed air' - the same air that Joseph Black discovered in 1755.

NEED TO KNOW

These 18th Century ideas will help you understand the story of fire

1 CALX

Chemists in the 18th Century defined calx as the substance obtained when phlogiston was driven out by heating or rusting: iron → calx (rust) + phlogiston. We now know that the reverse happens: oxidation. Oxygen reacts with iron to form the calx or rust.

2 FIXED AIR

The 18th-Century chemists called the air obtained by heating metals with charcoal 'fixed air'. It cannot sustain a flame or life. Today we know it as carbon dioxide. It is formed by the reduction of the metal ores (calx). In other words, the reaction between carbon and the oxygen in the ore.

3 REDUCTION

When ores are heated with charcoal in a furnace, according to the 18th-Century chemists, phlogiston passes from the charcoal to the calx, producing the metal. Again, they had it the wrong way round. Carbon reacts with the oxygen in a reaction that is the reverse of oxidation: reduction.

Lavoisier was convinced that the two processes were related, and exactly the opposite of what was predicted by the phlogiston theory actually happened. Combustion did not emit phlogiston into the air, but took something from it. The reduction of calx with charcoal did not absorb phlogiston but produced 'fixed air'.

Now Lavoisier set out to investigate the processes of reduction and combustion using the same material in a single experiment. It was known that if you heated mercury, it turned into a reddish calx called mercurius calcinatus. It would give off the dephlogisticated air, as shown by Priestley. Lavoisier confirmed the results of Priestley's experiment, and also found that the reddish calx formed in this 'calcination process' expelled air that made candles burn brightly.

Mercury became Lavoisier's choice for his next study (see 'The key experiment', p94). The result



The 17th Century alchemist Georg Stahl thought that lightning was the result of the substance phlogiston building up in the air

of this proved that 'common air' wasn't a single substance but had two components, one of which combined with the metal and was good for respiration. The other 'air' was bad for both respiration and combustion. In 1777, Lavoisier proudly announced it was oxygen and not phlogiston that caused combustion. Oxygen was air that was sharp ('oxy' in Greek) because it formed acids. The air we breathe, he reported, consisted of one-sixth oxygen and five-sixths 'azote' (from the Greek meaning "without life"). The inert gas had to be different from the 'fixed air' (carbon dioxide) because it did not turn limewater milky. His result was close to the truth – today we know that air contains 21 per cent oxygen and 78 per cent nitrogen.

Chemistry and physics were still insufficiently developed to understand the nature of flames. At the very same meeting at which he discarded

the idea of phlogiston, Lavoisier introduced another idea – caloric. This was an elastic fluid that permeates everything on Earth, flowing from warm bodies to colder ones. It was the first step towards a concept of energy, which developed during the 19th Century and helped banish many of the misconceptions in chemistry and physics. And at long last, fire was finally revealed as the effect of combustion under oxygen. ■

Alexander Helleman is the co-author of *The History Of Science And Technology*

Find out more



Listen to an episode of *In Our Time* on the discovery of oxygen with Melvyn Bragg and guests. <http://bbc.in/KeAboS>

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PICK OF THE MONTH



Royal Institution Christmas Lectures 2013

Dr Alison Woollard delivers this year's Christmas Lectures on how organisms develop

➔ **MUTANTS. THEY'RE EVERYWHERE.** On the buses, in the streets, lurking in the shops. In fact, you're probably sitting next to one right now. "We're all absolutely full of mutations," explains Dr Alison Woollard, the presenter of this year's *Royal Institution Christmas Lectures*. "We acquire them every day." But before you start panicking, most of them are harmless, and some are even useful.

To find out more, you'll have to watch this year's lectures, titled 'Life Fantastic'. The three programmes look at how organisms develop. At the heart of this story is a tiny structure that can be found in every living thing, from the lowliest bacteria to the largest whale: the cell.

"We all start off as one cell and then end up as a huge community of cells, all doing different things at different times," says Woollard. "All of our cells contain exactly the same DNA, so how do they all end up doing such different things?"

This million-dollar question is tackled in the first lecture: 'Where do I come from?'. In the second lecture, Woollard explores how changes within cells allow organisms to evolve over time – and that's where the mutants come in.

"Organisms acquire new characteristics when mutations cause their cells to become programmed in a slightly different way," says Woollard. "When a mutation makes the organism more likely to succeed, you have natural selection, making that organism's species evolve. In the lecture, we're going to focus on how changes in DNA can alter the way an organism looks."

Finally, in the third lecture, 'Could I live forever?', Woollard looks to the future. "When we understand what makes cells different, we can start to give them useful properties – turning stem cells into heart cells, for example." This will allow us to replace organs when they wear out – slowing, and even halting, the ageing process.

So we could all be immortal mutants... we wonder if the producers of the *X-Men* will be watching.

JAMES LLOYD



Watch the *Royal Institution Christmas Lectures* on BBC Four over the Christmas period

DON'T MISS!



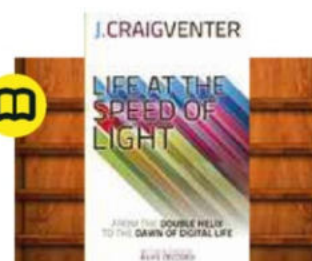
Stargazing LIVE

Join Brian Cox and Dara O Briain for a celebration of the night sky and the latest astronomy news. **p104**



Plagues

They've ravaged us through the ages, but how will infectious diseases affect our future? Find out with a series of talks. **p107**



Life At The Speed Of Light

Genetics pioneer Craig Venter's latest book is a look at the history of synthetic biology. **p108**



WATCH

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WITH TIMANDRA HARKNESS

FROM 12 DECEMBER

Plants Behaving Badly

Eden, starts 12 December, 7pm



SEX AND DEATH pervades the plant world in these two shows. First, the sordid world of the orchid, whose beauty seems pure but serves only one purpose: to lure insects. Once it's had its wicked, pollen-spreading way, the orchid never texts, never calls... In the second film, insects are demoted from pollinator to lunch (Venus flytrap pictured).

FROM 12 DECEMBER

Mankind: The Story Of All Of Us

H2, starts 23 December, 6pm



AN AMBITIOUS TITLE for an ambitious series, narrated by Stephen Fry. Science, history and geography are pulled in to tell the story of the rise and fall of civilisations. It's an action-packed epic, punctuated with key discoveries and developments that turned us from hunter-gatherers into settled societies who can sit in comfort and watch TV.

JANUARY

Crisis Control

Discovery, January TBC



SOMETIMES, FAILURE IS not an option. If you're responsible for the Panama Canal, for a major airport, or even a spectacular Las Vegas show, you need systems in place that can deal with anything. If they fail, thousands of people could die. This series goes behind the scenes to meet the people that keep everything running smoothly.

TIMANDRA HARKNESS is a stand-up comedian and a presenter on BBC Worldwide's YouTube channel Head Squeeze

EDITOR'S CHOICE



In an alternate Universe, Prof Brian Cox and Dara O Briain present a show about staying indoors and looking at the ground

FROM 7 JANUARY

Stargazing Live

BBC Two, 7, 8, 9 January, 8pm

BACK AGAIN FOR a fourth season, how can the live astronomy show reach new heights? For a start, by sending its presenters aloft. No, Dara didn't sneak himself aboard NASA's MAVEN mission to Mars – though he has a report from the launch – but he does experience zero gravity aboard a parabolic flight. Liz Bonnin ventures above the clouds, too, chasing the Northern Lights.

Prof Brian Cox is back with a new role as weather presenter – that's the space weather across the Solar System. And when he's not busy forecasting solar storms, he'll delve into some tricky theory. Will we ever use warp drive for

interstellar travel? What is dark energy? Why can't you get an overdraft from Jodrell Bank?

The studio guest list looks more impressive than ever, with celebrities and space scientists dropping in for a chat. Three generations of astronauts – past, present and future – will share their experience of leaving planet Earth behind. Meanwhile, amateur astronomers will be out in the cold to share some exciting new projects. Will you be one of the lucky local groups to get a turn controlling a powerful telescope? Or will you stay indoors and enjoy *Stargazing Live* from your own comfy sofa?

JANUARY

Horizon

BBC Two, January TBC



BBC'S *HORIZON* USHERS in the New Year. For the seasonal over-indulgers among us, twin GPs Chris and Xand Tullican ask: why has obesity become such a problem? Meanwhile, Iain Stewart travels to Florida to get to the bottom of the state's mysterious sinkholes (we hope not literally). The rest of the series looks at NASA's Martian ambitions, and more besides.

5 JANUARY

Miracle Landing On The Hudson

National Geographic, 5 January, 8pm



A DOUBLE BIRD strike within minutes of take-off is unlucky, but when it happened to US Airways Flight 1549 in January 2009, Chesley Sullenberger was at the controls. He beat the odds to bring the plane down in one piece on the river Hudson in New York. Reconstructions, interviews and expert opinions tell the story.

JANUARY

Big Brain Theory

Discovery Science, January TBC



Presenter Kal Penn should tell Buzz Aldrin he doesn't need the name tag anymore

→ FORGET *THE APPRENTICE*, *Scrapheap Challenge* or *Dragon's Den*. Over in the US, they like a bit more jeopardy in their TV. So the 10 contestants competing in this hunt for the new generation of technological minds face a few extra pressures. Like a 30-minute time limit to come up with an engineering solution to that week's challenge. This could be anything from replacing a bridge that's been blown up, to smashing two pick-up trucks into each other loaded with explosives, judged by people like Buzz Aldrin.

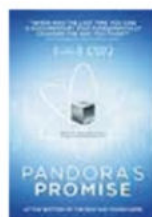
DVD & BLU-RAY



Earth From Space

Spirit Entertainment, DVD, £12.11

WITH SO MANY satellites orbiting our home planet, we have unprecedented abilities to observe the Earth. This film uses footage taken from space, from closer to home, and from scientific observations, combined with CGI to deliver an all-encompassing examination of our world.



Pandora's Promise

November Films, DVD, £8.99

NUCLEAR POWER – WHERE do you stand? Dangerous technology that should be abandoned? Or potential saviour in our quest for low-carbon energy sources? This film goes right to the heart of the controversy, interviewing energy experts and environmentalists.



Leviathan

Dogwoof films, DVD, £10.59

THIS DOCUMENTARY IMMERSSES you in the dangerous world of commercial deep-sea fishing. Literally immerses you, at times, as the camera dives below the waves. At other times, a bird's-eye view reveals the isolation of the vessel in an unforgiving environment.

13 JANUARY

Meteor Strike

National Geographic, 13 January, 10pm



The fireball seen streaking over the Russian city of Chelyabinsk last February was a space rock. When it blew apart, it unleashed forces equivalent to 30 Hiroshima bombs. Thanks to the Russian habit of video recording from their vehicles, this programme has plenty of striking footage to supplement the astronomy behind the fireball.

13 JANUARY

Ice Tsunami

National Geographic, 13 January, 10.30pm



WATER CAN BE swift and deadly, as tsunamis remind us only too often. But ice moves slowly – at glacial speeds – right? Not always. In May 2013 a fast-moving wall of ice tore through communities in Canada and the US. Amateur film helps experts explain how it happened. It will also remind you to defrost your freezer before it's too late.



LISTEN

BBC RADIO PROGRAMMES
WITH TIMANDRA HARKNESS

18 DECEMBER

Frontiers

BBC Radio 4, 18 December, 9pm

WILL YOU BE in your mid-evening stride when this programme goes out at nine, or yawning and planning to catch it on iPlayer at six tomorrow morning? Linda Geddes discovers the science of body clocks with the scientists who are sorting us into larks and owls. Whether you're an early-bird or a night-hawk may depend on your biology as much as your habits.

31 DECEMBER

All In The Mind

BBC Radio 4, 31 December, 9pm

THE PSYCHOLOGY, psychiatry and brain science series returns with some surprising new findings about cognitive fatigue – Samuele Marcora of the University of Kent has trained soldiers to resist the physically tiring effects of too much hard thinking. Also, moral distress and the results of the 2011 BBC Stress Test.

1 JANUARY

Show Me The Way To Go Home

BBC Radio 4, 1 January, 9pm

YOU MAY NOT recognise the name Ruth Brooks, but if we say she's the Snail Lady who won BBC Amateur Scientist of the Year 2010, your memory may travel back to her research into hungry gastropods finding their way back to her garden. Having established that snails can make a comeback from as far as 10 metres, she's moved



The Snail Lady's next challenge: newts

on to other animals. How do newts navigate? Can cats read maps? Find out here.

JANUARY

The iPod War

BBC World Service, January TBC

TWO MAJOR DEVELOPMENTS launched in October 2001: the iPod and the war in Afghanistan. Coincidence, but the bulletproof music device is the item most often requested from Help for Heroes to boost the morale of those serving in the UK forces there. Psychologists and those on the front line contribute to this hour-long special exploring the symbolism and the practical role of the iPod at war.



JANUARY

The Human Zoo

BBC Radio 4, January TBC

MICHAEL BLASTLAND'S series asking how we think returns for a third season, with expert input from psychologist Nick Chater of Warwick University. This time, as well as joining in online tests, you can hear the results of live experiments conducted on volunteer listeners. Plus the usual mix of interviews, investigations, studio discussion and current affairs. And Timandra Harkness. Again.



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PHYSICS IS EASY once you've mastered the basics and committed to memory every rule and theory. For most of us, however, remembering all the details can be tricky. iPhysics Pro is an app designed to gently introduce key concepts and reinforce your knowledge of

physics to keep with you wherever you go. The app covers motion, gases, liquids, thermodynamics and more in an easy to navigate and, importantly, digestible format.

Walking With Dinosaurs

iPhone, iPad, and iPod touch
BBC Worldwide, free



THIS IS A truly stunning app that brings dinosaurs to life before your eyes. Print out a 'target sheet', place it on a flat surface and then open the app to see a 3D dinosaur. Complete with appropriate noises,

you can control up to two dinosaurs as they walk around your desktop. Feed the beasts as they explore their 3D habitat. Really impressively, you'll see them wander off the edge of the sheet, leaving footprints and casting shadows as they go.

Seene

iPhone, iPad, iPod touch, iOS 6 or later
Obvious Engineering, free



Seene lets you capture images and explore them in 3D. Thankfully no special glasses are required. It's a fun way to see how 3D images are created and your human subjects will no longer be able to simply present their 'best side'. The process is slightly more involved than just taking a picture – you have to capture the object from specific angles to make it work. Once you've made your 3D image, tilt your iOS device to see the effects. It may be something of a novelty, but there's some clever tech behind it.

CHRISTOPHER BRENNAN is a technology journalist and mobile app expert



VISIT

EVENTS & EXHIBITIONS
WITH JHENI OSMAN

20-22 DECEMBER

Curiosity Roadshow

Camden Lock Market, London, free, www.wellcomecollection.org

HOP ABOARD THE bus parked at Camden Lock Market and you can get your mitts on unique objects from the Wellcome Collection. You can also watch retro films and delve through archive images.

21 DECEMBER

Royal Observatory Greenwich Christmas Lecture

Royal Observatory Greenwich, London, 7-9pm, £6/£8, www.rmg.co.uk

DISCOVER THE ALIEN worlds and celestial bodies that fill our Galaxy at this talk by astrophysicist John Gribbin.

14 JANUARY

Wallace And The Limits To Evolution

Wallace Lecture Theatre, Cardiff University, 6:30pm, free, www.cardiff.ac.uk

STEVE JONES, THE well-known geneticist looks at the life of biologist Alfred Russel Wallace and his evolutionary ideas.

18 JANUARY

Behind The Lens: Wildlife Photographers

Natural History Museum, London, 12:30pm and 2:30pm, free, www.nhm.ac.uk



MEET PROFESSIONAL WILDLIFE snappers and hear about the lengths they go to in the hunt for that perfect shot.

20 JANUARY

Rosetta Space Night

Life Science Centre, Newcastle, 6-9pm, £2.70/£3, life.org.uk



CELEBRATE THE 'wake up' of comet-chaser Rosetta with an astronomy themed evening, as the craft comes out of hibernation.



EDITOR'S CHOICE

17 JANUARY - 7 MARCH

Plagues

Lady Mitchell Hall, Cambridge, Fridays, 5:30pm, free, www.darwin.cam.ac.uk



THEY'VE STOPPED ARMIES in their tracks and altered the fate of nations. This series of talks looks at all the repercussions of plagues. How did ancient plagues influence medicine? How do insect plagues affect our agriculture and economy? How will Earth cope with the 'human plague'? And what sort of plagues can we expect in the future now that the digital world has created a global network for computer viruses, malware and spyware, which threaten personal privacy and the security of nations? Don't have nightmares!

22 JANUARY - 14 FEBRUARY

Out Of Ice

Ambika P3, University of Westminster, London, free, p3exhibitions.com

MOST OF EARTH'S ice is locked away in Antarctica, but if other ice sheets melt, sea levels will rise by up to 95cm by 2100. Artist Elizabeth Ogilvie shows the threat ice loss poses to our planet.

23 JANUARY

Motion Perception Dialogue Event

7-9pm, free, www.sciencemuseum.org.uk

ARTIST MATT PYKE explains why cosmetic surgery can make you look creepy, and why we find human-looking robots, like the one pictured, scary.



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JHENI OSMAN is a science writer and the author of *100 Ideas That Changed The World* (BBC Books, £9.99)



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Life At The Speed Of Light

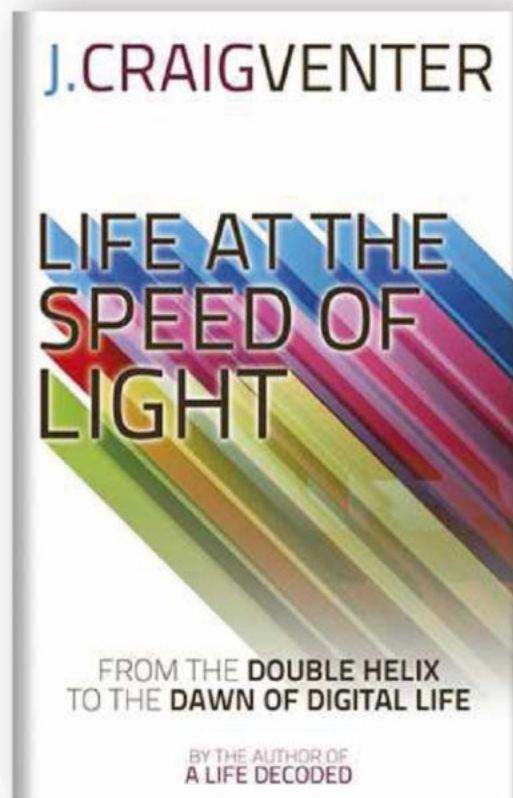
From The Double Helix To The Dawn Of Digital Life

J Craig Venter
Little, Brown £20

THE NORMALLY DEMURE magazine *Scientific American* described geneticist J Craig Venter in 2010 as '...the Lady Gaga of science. Like her, he is a drama queen, an over-the-top performance artist with a genius for self-promotion.' Venter, to the best of my knowledge, is yet to make a public appearance in a lab-coat made of raw meat. He is more nuanced than this sketch, and his contribution to modern biology should not be underestimated. *Life At The Speed Of Light* is the account of his scientific journey, treading a thorough chronology of biological engineering from its mid-20th century roots to now, though it focuses specifically on his own work in manipulating DNA into writable software.

The flap biography starts with the legend 'Venter is best known for sequencing the human genome', which grates given how many people were involved in both his private consortium and its more successful publicly owned competitor. But I would say that he is best known for the dervish of publicity (including the Lady Gaga quotation) that was whipped up after his publication of 'Synthia', a bacteria whose genome was constructed in a computer. This was a colossal technical achievement, expensive and lengthy, complete with hubristic

"Venter is best known for 'Synthia', a bacteria whose genome came from a computer"



quotations encoded within its DNA (he elects not to mention how one out of the three quotations was wrong, and another potentially infringed copyright). However, it was not the great heralding of the new synthetic biology that some proclaimed.

Venter is divisive; courting the limelight has earned him bogeyman status for many, and a distraction from other less attention-seeking work. His is no doubt important: in genomics, he has led teams that invented many new techniques, and his competition drove the public Human Genome Project forward.

The writing is very American: somewhat breathless, without a great presence of humility, but with a determined biographical narrative. Every page is encumbered with intellectual ancestors - 67 individuals name-checked in the first 23 pages, and across the whole book he references the Nobel Prizes of 33 laureates with almost comic regularity. Frequently, it reads as though each one is an inevitable part of the scientific family tree that expressly leads to the as-yet Nobel-less Venter. Whether he will be written about in the same terms is yet to be seen.



ADAM RUTHERFORD is the presenter of *Inside Science* on BBC Radio 4

MEET THE AUTHOR



Craig Venter

What's the meaning behind the book's title?

As we read the genetic code and digitise it, we can actually send that information through the internet. We've designed and built the first version of a 'Digital Biological Converter' where we take that computer information and robotically convert it back into the software of life. For example, Chinese scientists recently sequenced the H7N9 flu virus. We downloaded that information from the internet and synthetically made the virus, which can now be used to rapidly develop new vaccines ready for any pandemic.

Which of your achievements are you most proud of?

I'm very proud of doing the first genome of a living organism, and how that led to the human genome. But I think that our creation of the first synthetic cell will have even greater implications for humanity. When we made the first synthetic chromosome, we created a cell that was controlled and driven only by that chemically made piece of DNA. Life is a DNA software system, and if you change that software you can change the species.

How far away are we from creating complex animals like humans?

We're a long way from that. The mammalian genetic code is substantially larger than that of relatively simple bacteria. We have six billion letters of code in each of our cells, whereas the bacteria we made only had 1.1 million. The rules and regulations inside the cell get much more complex too. We're still at the very early stages of truly understanding human biology, so we're definitely not ready for synthetic humans.



MORE ON THE PODCAST

Listen to the full interview with Craig Venter at sciencefocus.com/podcasts



EDITOR'S CHOICE

Nothing

From Absolute Zero To Cosmic Oblivion

Jeremy Webb (Ed.)

Profile Books **P** £7.99

A BRAND OF painkillers used to be advertised on telly with the slogan 'Nothing acts faster than Anadin'. This always prompted my mum to say "So take nothing then!" Now it seems this old joke may be no laughing matter. New research suggests many 'proven' painkillers may really be doing nothing apart from triggering a placebo effect, which stimulates the body's own pain-killing system.

This is just one of a host of curious insights in this entertaining collection of essays on the theme of, well, nothing, compiled by Jeremy Webb, editor-in-chief of the obscure magazine *New Scientist*. Covering everything from physics to physiology, there's something for everyone. I expected to find the essays on mysteries like dark energy – the cosmic force that emerges from the 'nothing' of space – most interesting. Yet it was the more down-to-earth stuff I found more rewarding, like Andy Coghlan's essay about the health dangers of doing nothing. Even a bit of exercise, like walking round your sofa during TV ad breaks, can improve your life expectancy. Overall, this is a rare example of where it's worth paying something for nothing.

ROBERT MATTHEWS is a Visiting Reader in Science at Aston University, Birmingham



A Female Genius

How Ada Lovelace Started The Computer Age

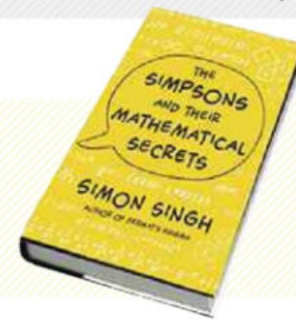
James Essinger

Gibson Square **H** £14.99

ADA, COUNTESS OF Lovelace was a mathematician and collaborator of the computer pioneer Charles Babbage. She has a programming language, Ada, named after her by the US Department of Defense in the 1970s; a medal in her name awarded by the British Computer Society since 1998; and an annual day, 15 October, recently named in her honour for the celebration of women scientists. Ada is also known as the sole legitimate child of the poet Lord Byron – she died at the same young age (36) as Byron.

Despite her deserved fame, Lovelace's vaunted stature as the first computer programmer is disputed, because Babbage was unable to build his complicated and expensive 'Analytical Engine' and thereby test her ideas. Even so, author James Essinger makes an appealing case for Lovelace as a visionary in this biography. For example, she 'foresaw the digitisation of music as CDs or synthesizers and their ability to generate music', he writes. However, the book's title is too much of a stretch. 'Genius', whatever its gender, can only properly be ascribed to those who manage to bring their ideas to fruition, such as Alan Turing.

ANDREW ROBINSON is the author of *Genius: A Very Short Introduction*



The Simpsons And Their Mathematical Secrets

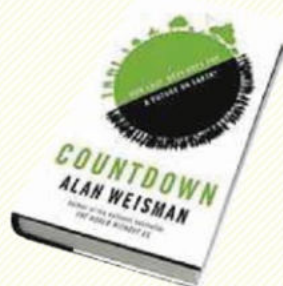
Simon Singh

Bloomsbury **H** £18.99

EPISODES OF *THE Simpsons* are full of maths. As Simon Singh reveals, its writers – who between them have Masters degrees and PhDs from some of the world's top maths departments – have snuck in concepts ranging from statistics to geometry. Recounting episodes, Singh picks apart each blink-and-you'll-miss-it reference: why the Universe might be doughnut-shaped; and how one of the great theorems, Fermat's Last Theorem, can be proved wrong.

Unfortunately, the links between cartoons and conjectures sometimes feel forced. There is little to motivate a section about game theory, and 'Simpson's paradox' is covered only because it shares the show's name. The best bits are the behind-the-scenes stories, such as when the writers came up with mathematically intriguing numbers for a brief shot of a scoreboard; or when the makers of *Futurama* – *The Simpsons'* sister show – developed a theorem to ensure that a loose plot could be tied up neatly. Often the writers put a huge effort into an idea just because they find it interesting. By explaining why, Singh shows just how addictive maths can be.

ADAM KUCHARSKI has a PhD in maths and is an award-winning science writer



Countdown

Our Last, Best Hope For A Future On Earth?

Alan Weisman

Little, Brown **H** £25

EVERY FOUR AND a half days sees a million more people born on a planet that's not getting any bigger and whose resources are running out. As we're easily desensitised to such statistics, Alan Weisman surveys overpopulation from the points of view of dozens of personal stories. He takes us from Japan, whose population is sliding towards extinction yet whose youngsters have given up sex, to the expanding deserts of Niger where local chieftains no longer see children as a blessing.

One lesson sings out from this perhaps overlong catalogue of detail, and it is this: it is women who will save the world. When

women are freed from the reproductive tyrannies of religion and society they have fewer children, and educated women have the fewest children of all. Were all the world's women to average between one and two children, the world's population could ebb before 2100. Perhaps these women, more than today's discredited and mainly male bankers, will work out how we're to embrace the zero-growth economy we'll need if we're to survive on this planet.

HENRY GEE is an evolutionary biologist and a senior editor of the journal *Nature*

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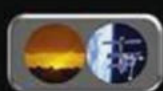
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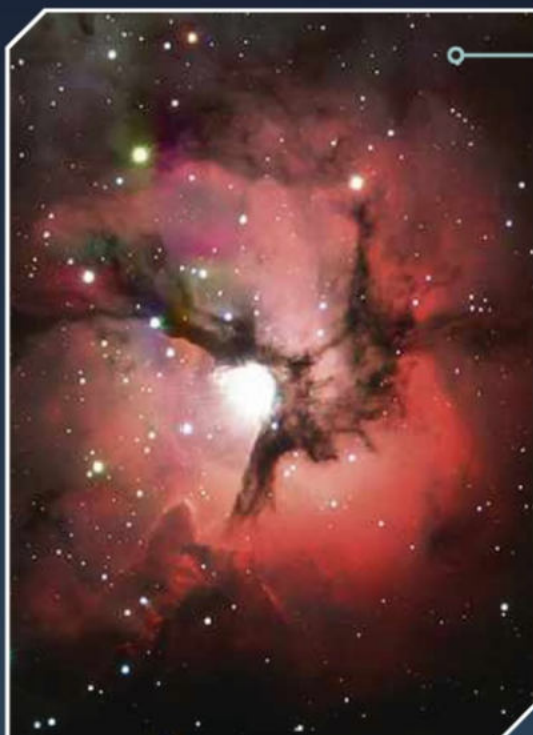
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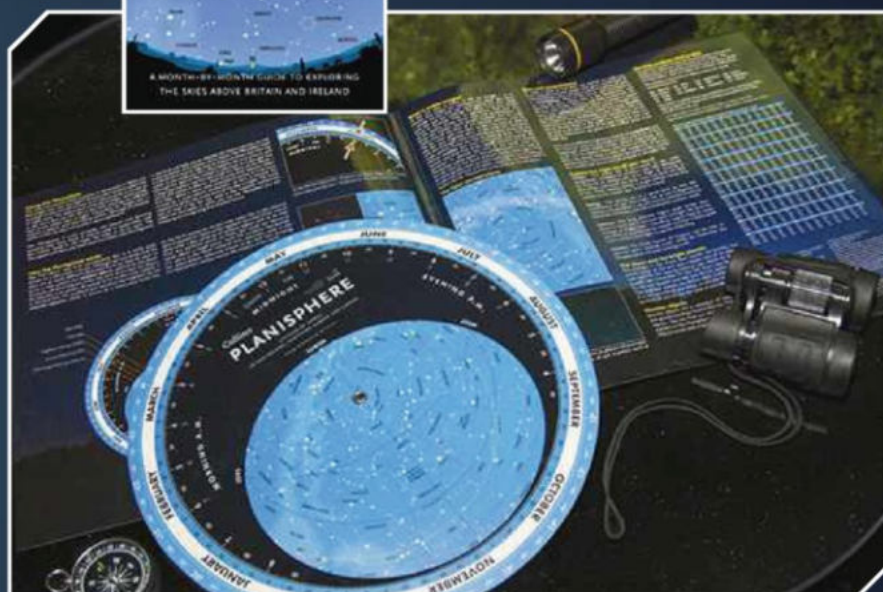


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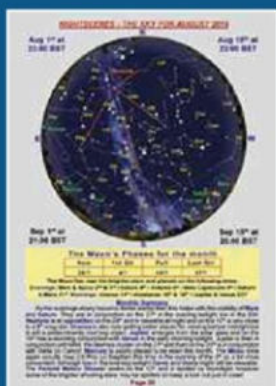
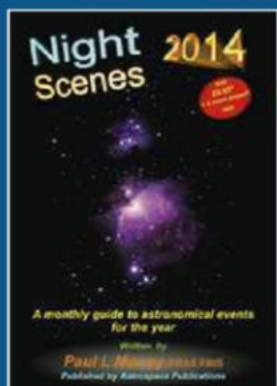


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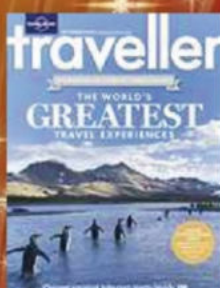
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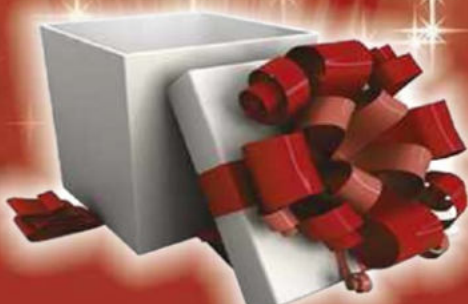


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MINDGAMES



Pit your wits against these brainteasers by David J Bodycombe, question-setter for BBC Four's *Only Connect*

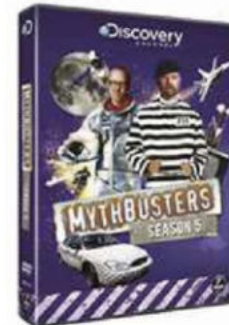
PRIZE PUZZLE

At the front they are black and white, or black and yellow at the rear. They have the power to evoke pride or amusement, and can be bought and sold for six-figure sums. However, if they break they can be replaced for £20. What are they?

WIN! MYTHBUSTERS SEASON 5

The first five correct entries win a copy of *MythBusters Season 5* on DVD (Discovery, £21.24).

Post your entry, marked 'Prize Puzzle 263', to: *BBC Focus Magazine*, PO Box 501, Leicester, LE94 0AA, to arrive by 5pm on 9 January 2014. We regret that we cannot accept email entries for this competition. See sciencefocus.com/winners for a list of previous winners and solutions.



See bottom of p113 for terms and conditions. Congratulations to Kevin Ward (Gloucestershire), Kathy Humphrey (Crewe), Jacqui Sclanders (Lincolnshire), Anne Miller (West Yorkshire) and Jo Dale (Lancaster) who answered October's Prize Puzzle correctly to win a copy of *How We Invented The World*.

Q1

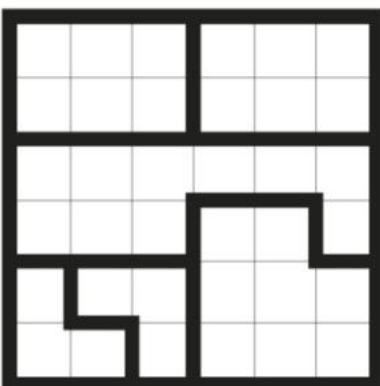
In the early days of train travel, Third Class carriages had holes drilled in the floor. For what reason?

Q2

When divided by 2, 3, 4, 5 or 6, this number leaves a remainder of 1. When divided by 11, it leaves no remainder at all. Find the number.

Q3

Shade in six small squares so that each row, column and outlined region contains one shaded square. No two shaded squares touch, not even diagonally.



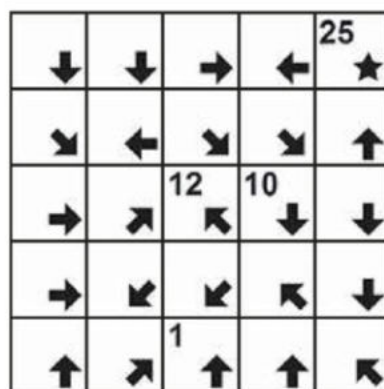
Q4

Triton, Titania, Titan, Ganymede, Phobos... what comes next, and why is that the end of the sequence?

Q5

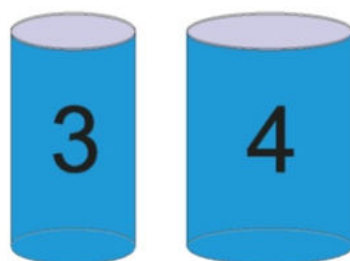
Number every square so that it is possible to travel from 1 to 25. When you land on a square, the next square

must be somewhere along the direction indicated (not necessarily the immediately adjacent space).



Q6

You have two full open-topped cylinders containing 3 and 4 litres of water respectively. Without using anything else, how can you make the larger cylinder contain approximately 'pi' litres?

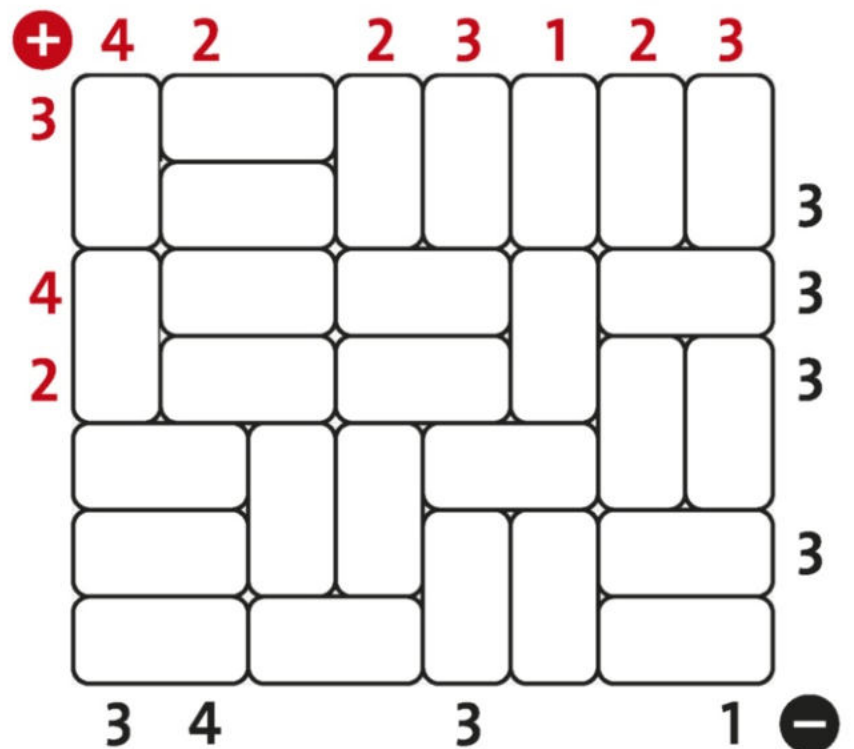


Q7

A town in Kent just north of Dover; a high-jumping technique; a 'go' in a game... what could come next?

Q8

Each rectangle contains either a battery with a **positive (+)** and negative (-) pole OR a dud wooden block which does nothing. The **red/black** numbers indicate how many **positive/negative** poles there are in that row or column. Two like poles (eg + and +) cannot touch, horizontally or vertically.



SOLUTIONS

Q1) To let the rain drain away. The Third Class carriages had no roof.
Q2) The lowest common multiple of 2, 3, 4, 5 and 6 is 60. Now try multiples of 60 with 1 added to it. 61 isn't a multiple of 11. However $(2 \times 60) + 1 = 121$, the required answer.
Q3) Row by row, shade the 5th, 2nd, 6th, 4th, 1st and 3rd square.
Q4) Earth's Moon - they are the largest natural satellites of each planet in Solar System order.
Q5) Row by row: (20, 4, 2, 3, 25); (14, 13, 9, 16, 24); (7, 8, 12, 10, 17); (21, 5, 22, 11, 18); (6, 23, 1, 15, 19).
Q6) Tip the 3L cylinder until the water level just touches the bottom edge - this half-empties it, leaving 5.5L in total.
Q7) The Thames or any other river - they are the stages of a Texas Hold 'Em poker hand: Deal, (Fosbury) Flop, Turn, River.
Q8) See illustration on p121.

QUICK QUIZ

Take a test to see how much you know about mammals

Q1

Roughly how long ago did the first mammals appear?

- a) 100 million years
- b) 150 million years
- c) 200 million years

Q2

Which species of whale is the largest mammal in the world?

- a) Sperm whale
- b) Blue whale
- c) Killer whale

Q3

What's the scientific name for a mammal that lays eggs?

- a) Monotreme
- b) Ovumate
- c) Cetacean

Q4

Complete the sentence: 'Bats are the only mammals...'

- a) ...with wings
- b) ...that eat insects
- c) ...that hunt at night

Q5

On which continent are most marsupials found?

- a) South America
- b) Asia
- c) Australia

Q6

Which mammal is also known as the sand puppy?

- a) Naked mole rat
- b) Antelope squirrel
- c) Caracal

Q7

Roughly how long is an Asian elephant's gestation period?

- a) 600 days
- b) 650 days
- c) 700 days

ANSWERS:

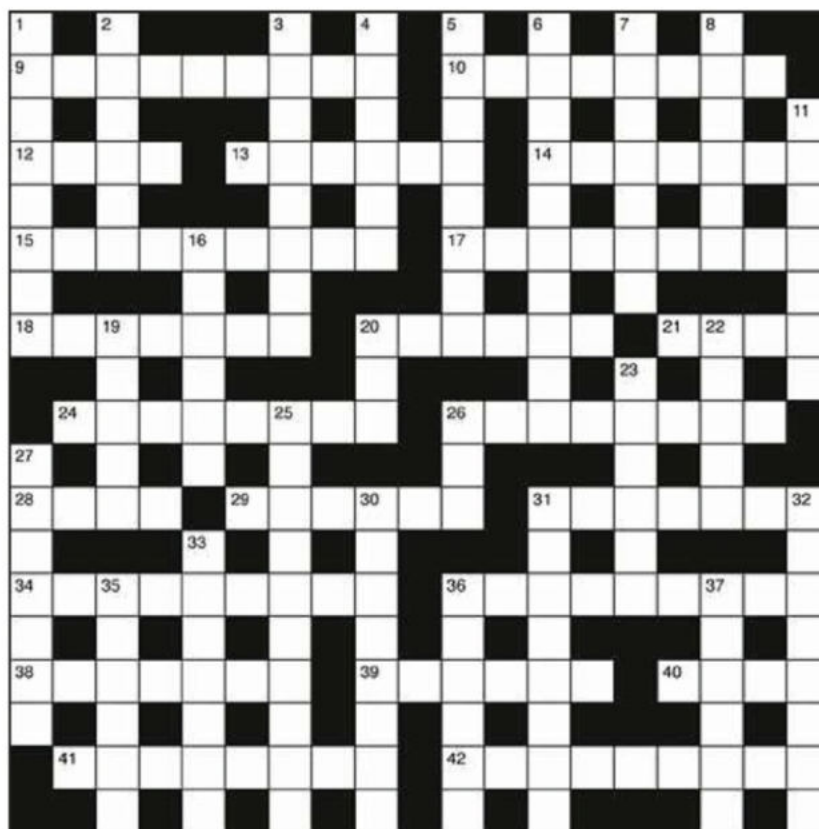
1c, 2b, 3a, 4a, 5c, 6a, 7b

YOU ARE:

- 0-3 Blind as a bat
- 4-5 Keeping the wolf from the door
- 6-7 The dog's proverbials

FOCUS CROSSWORD No 159

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ACROSS

- 9 Partial to small overtones (9)
- 10 Her inept use of a surgical instrument (8)
- 12 Managed to capture old horse (4)
- 13 Friends getting into shape (6)
- 14 Copper has bread mixed with a dye (7)
- 15 A quiet errand boy has to finish supplement (9)
- 17 Range of frequencies gives group scope (9)
- 18 Chemical substance that provides heat (7)
- 20 I'd go back to king with rubbish decree (6)
- 21 Mark's out of mascara (4)
- 24 Projectile at home makes the news (8)
- 26 Take a rug to wrap extinct creature (5,3)
- 28 One boisterous start by old goat (4)
- 29 Snake volunteers to generate pain (6)
- 31 Windpipe changes in each rat (7)
- 34 Shyness - it improves by combining (9)
- 36 Piano rags composed from bits of fungi (9)
- 38 Complaint as construction coils round it (7)
- 39 Enjoy chutney (6)
- 40 Rendered ill by unknown plant (4)
- 41 Reserve shown by spineless person and a good reader (8)
- 42 Clever nit displayed a bit of heart (9)

DOWN

- 1 Around the road, swarming, like most animals (8)
- 2 Pear recipe gave politician a booster (6)
- 3 Bit nails terribly while hissing (8)
- 4 Spy turned out to have revolutionary mind (6)
- 5 Betokens new antelope (8)
- 6 Centre page out of proportion (10)
- 7 Obscure how days are changing (7)
- 8 Inexpert, under a new spell (6)
- 11 Throwing a cherry for sport (7)
- 16 Irritate with a hypodermic (6)
- 19 Piece of duet performed with energy (5)
- 20 Nod back at the professor (3)
- 22 Black bird lost second sign of illness (5)
- 23 Arts perplex, thanks to having layers (6)
- 25 Semiconductor should sort strain out (10)
- 26 Information in an emergency (3)
- 27 Critically examine woman's group (7)
- 30 Imparts a new filling (8)
- 31 Grand amount (8)
- 32 Learn, say, about examiner (8)
- 33 Altered his opinion of fungus (7)
- 35 Hold an admiral (6)
- 36 Lisa sent Virginia a secretion (6)
- 37 Difficulty in German left an irritation (6)

SOLUTION TO CROSSWORD No 156

Sue Corbett, Phillip Glendinning, M Hodgson, Peter Haworth and Peter Hodgkinson (Doncaster) solved issue 260's puzzle and each receive *MythBusters Season 2* on DVD.



WIN! MICRO MONSTERS 3D ON BLU-RAY

The first five correct solutions drawn will each win a copy of *Micro Monsters 3D With David Attenborough* (Sky 3D, £13.19). Entries must be received by 5pm on 9 January 2014. See below for more details.



YOUR DETAILS

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POSTCODE

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Post entries to BBC Focus Magazine, January 2014 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to january2014@focuscomps.co.uk by 5pm on 9 January 2014. Entrants must supply name, address and phone number. By entering, participants agree to be bound by the terms & conditions, printed on p121. Immediate Media, publisher of BBC Focus Magazine, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

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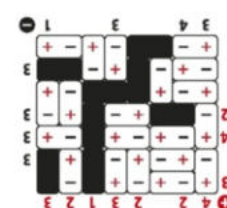
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MINDGAMES PUZZLE SOLUTION
No cheating! Don't look at this until you've attempted the puzzle on p117.

HOLLYWOOD SCIENCE

ALERT!
CONTAINS
PLOT SPOILERS

Separating science fact from movie fiction

PACIFIC RIM

THE PERENNIAL DEBATING game down the pub is: who would win in a fight? A 76m-tall (250ft) robot or a pan-dimensional giant amphibian bred for wiping out mankind? Your money's on the robot, right? But what if the giant monsters just keep getting bigger and bigger? This is the premise of director Guillermo Del Toro's *Pacific Rim*. Humanity are pitted against the Kaiju, an army of ever-growing behemoths hundreds of metres tall, who like nothing more than snacking on high-profile landmarks while they slug it out with the Jaegers, giant robots that act as mankind's last line of defence.

But how big could the Kaiju, or any creature, really get before physiological limits get in the way? Galileo may well have been thinking about the problem in 1638 when he formulated the square-cube law. Say an animal doubles in size. Its volume becomes cubed while its surface area is only squared. This creates all sorts of problems. Bones, with only four times the surface area, are subject to eight times the weight. So the Kaiju would be at increased risk of broken bones, and fitting a plaster cast on something that angry would be dangerous. Muscles and cartilage are

“The largest land animal possible would weigh somewhere between 100 and 1,000 tonnes”

likely to fail. With a lot of bulk and comparatively little skin, overheating is also likely to be a problem, as is delivering oxygen around its enormous frame. “Something is going to give,” says dinosaur expert Mike Taylor from Bristol University, “the question is, what will fail first?”

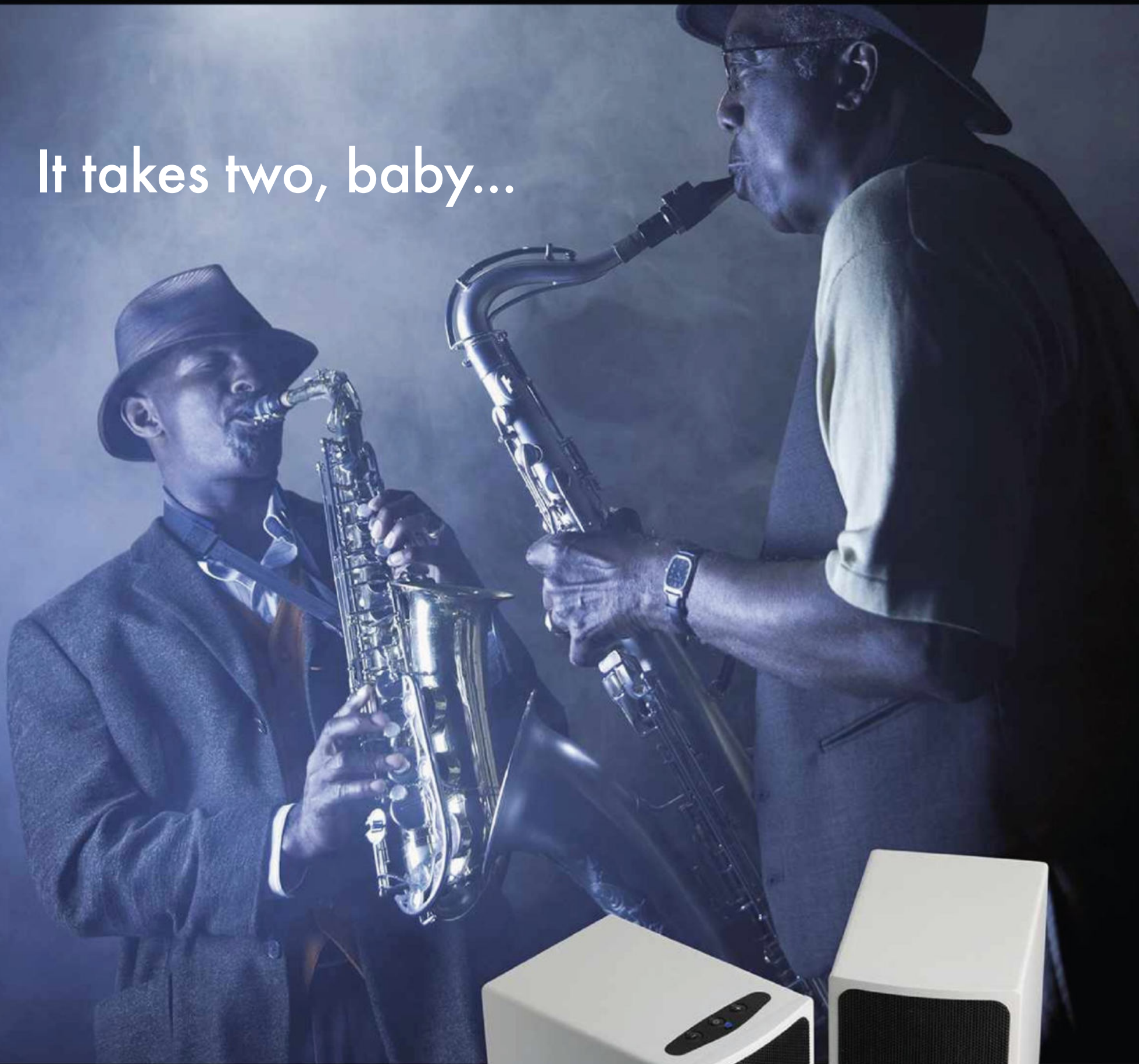
A blue whale, the largest ever living animal weighing in at up to 170 tonnes, shirks the square-cube problem by using the protective buoyancy of the oceans to help support its weight. Dinosaurs, the world's largest terrestrial animals, circumvented these problems by being uniquely adapted to being big. The 80-tonne, long-necked *Argentinosaurus* had an efficient bird-like respiratory system that would have drawn in oxygen whilst breathing in and out. It swallowed without chewing to gulp down the

tonne of food it needed per day to nourish its giant frame. It also boasted air-filled bones to lighten its load, a comparatively tiny head that didn't crush its neck, and four vertical limbs to help support its weight.

Taking all the various factors into account, researchers have estimated that the largest land animal possible would weigh somewhere between 100 and 1,000 tonnes – not the several thousand tonne bulk of the Kaiju. “It's just completely unfeasible,” says Taylor. Of course, these size limitations might not apply to a creature of dubious alien biochemistry that bleeds ammonia and can self-destruct, but for now at least, it's comforting to know the Kaiju remains relegated to the realms of B-movies. ■

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